ADA033827

USAAEFA PROJECT NO. 74-23

HANDLING QUALITIES EVALUATION
OH-58A HELICOPTER INCORPORATING A MINISTAB 3-AXIS STABILITY AUGMENTATION SYSTEM

FINAL REPORT

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FEBRUARY 1975

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER USAAEFA PROJECT NO. 74-23	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) HANDLING QUALITIES EVALUATION, OH-58A HELICOPTER INCORPORATING A MINISTAB 3-AXIS STABILITY AUGMENTATION SYSTEM.		5. TYPE OF REPORT & PERIOD COVERED FINAL REPORT. 20 July - 24 August 1974. 6. PERFORMING ORG. REPORT NUMBER USAAEFA PROJECT NO. 74-23
7. AUTHOR(s) (10) EDWARD E. BAILES, MAJ CARL F. MITTAG, ROBERT M. BUCKANIN		8. CONTRACT OR GRANT NUMBER(s) (14)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AIR FORCE BASE, CALIFORNIA 93523		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS EJ4H004400EJEJ
11. CONTROLLING OFFICE NAME AND ADDRESS US ARMY AVIATION ENGINEERING FLIGHT ACTIVITY EDWARDS AIR FORCE BASE, CALIFORNIA 93523		12. REPORT DATE (11) FEBRUARY 1975 13. NUMBER OF PAGES 62 (12) 62p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Light helicopter stability augmentation system (SAS)
OH-58A helicopter
Societe Francaise d'Equipements pour la Navigation Acrienne (SFENA) SAS
Three-axis Ministab SAS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A limited handling qualities evaluation of the OH-58A helicopter incorporating the SFENA 3-axis stability augmentation system called Ministab was performed by the United States Army Aviation Engineering Flight Activity at Edwards Air Force Base, California. The system identified as the SFENA Ministab stability augmentation system was manufactured by the Societe Francaise d'Equipements pour la Navigation Acrienne (SFENA) of France and made available for test by

(continued)

19. Key words

Bell Helicopter Company 3-axis stability and control augmentation system
Instrument flight requirements
Limited aircraft handling qualities evaluation

20. Abstract

Kaiser Aerospace and Electronics Corporation of Palo Alto, California, who also installed and maintained the system during testing. The testing consisted of 11.2 productive flight hours and was conducted from 20 July through 24 August 1974. This evaluation was of limited scope and consisted of both quantitative data and qualitative pilot comments. The test results show significant improvements in the aircraft handling qualities with the addition of Ministab. The most significant improvements provided by the system were (1) improved lateral-directional stability, (2) improved in-ground-effect hover handling qualities, (3) constant heading during ±10-psi power changes while hovering, (4) improved directional stability during pop-up and bob-up maneuvers, and (5) improved handling qualities during terrain-following. Three shortcomings were noted: (1) excessive directional oscillations during 20-knot left sideward flight with Ministab ON, (2) high roll rate combined with pitch coupling following a Ministab roll axis hardover, and (3) insufficient aft longitudinal control resulting from a forward hardover in rearward flight. A qualitative comparison between Ministab and the Bell Helicopter Company 3-axis stability and control augmentation system (SCAS) indicated improved stability during maneuvering flight, although a decrease in controllability was noted. The attitude retention capability incorporated by Ministab, and not available with the Bell SCAS, was qualitatively assessed during precision flight and a decrease in pilot workload was observed.

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INTRODUCTION

BACKGROUND

1. The Kaiser Aerospace and Electronics Corporation of Palo Alto, California, offered the United States Army Aviation Systems Command (AVSCOM) the opportunity to evaluate a stability augmentation system (SAS) manufactured by the Societe Francaise d'Equipements pour la Navigation Aerienne (SFENA) of France. The SAS, called Ministab, was designed for installation in light helicopters. The United States Army Aviation Engineering Flight Activity (USAAEFA) was subsequently directed by AVSCOM (ref 1, app A) to conduct an evaluation of the Ministab SAS installed in an OH-58A helicopter. The Ministab SAS was installed and maintained by Kaiser personnel during the conduct of the test.

TEST OBJECTIVES

2. The objectives of this test were as follows:

a. To quantitatively evaluate the handling qualities of an OH-58A helicopter incorporating the 3-axis SFENA Ministab SAS with respect to the instrument flight requirements of military specification MIL-H-8501A (ref 2, app A).

b. To compare flight test data between the SFENA Ministab SAS and the Bell Helicopter Company (BHC) 3-axis stability and control augmentation system (SCAS) previously tested during the conduct of USAASTA Project No. 72-20 (ref 3, app A).

DESCRIPTION

3. The test aircraft, an OH-58A light observation helicopter, serial number 68-16706, was manufactured by BHC. It has a single two-bladed, semirigid, teetering main rotor and an antitorque tail rotor. The tail rotor also has a delta-three hinge. The cockpit provides side by side seating for a crew of two (pilot and copilot/observer) and the cargo compartment has seats for two passengers. Dual flight controls are provided. The cyclic and collective controls are hydraulically boosted and irreversible, while the directional controls on the standard configuration OH-58A are unboosted. The landing gear consists of fixed skids. The helicopter is powered by an Allison T63-A-700 free gas turbine engine with a takeoff power rating of 317 shaft horsepower (shp) at sea-level, standard-day uninstalled conditions. The main transmission has a rating of 270 shp for continuous operation, with a takeoff power limit of 317 shp (5-minute rating). A detailed description of the standard OH-58A may be found in the operator's manual (ref 4, app A). The test aircraft was modified with hydraulically boosted directional controls and

a Ministab 3-axis SAS. The standard force trim system was replaced with a force trim system incorporating control motion transducers and increased force gradients (cyclic control only). A cockpit control panel allowed selection of directional SAS, cyclic SAS (pitch and roll), or simultaneous operation of both. Pitch and roll channels could not be selected independently. A detailed description of Ministab is given in appendix B.

TEST SCOPE

4. The handling qualities of the OH-58A helicopter equipped with Ministab were evaluated by USAAEFA personnel at Edwards Air Force Base, California, from 20 July through 24 August 1974. Eleven test flights for a total of 11.2 productive hours were flown. Flight limitations contained in the operator's manual and the safety-of-flight release (ref 6, app A) were observed during the testing. Test conditions are shown in table 1. Although the basic OH-58A was not designed for instrument flight, the aircraft with Ministab installed was tested for compliance with the instrument flight requirements of MIL-H-8501A. Additionally, test results were compared with the test results obtained during the conduct of USAASTA Project No. 72-20, *Handling Qualities Evaluation of the OH-58A Helicopter Incorporating the Model 570B Three-Axis Stability and Control Augmentation System*. Precise comparison between the Ministab and the BHC SCAS was not possible because the greater weight of the instrumentation package for the Ministab evaluation caused a forward center-of-gravity (cg) condition. In addition, the high density altitudes of the test site during testing required operating the test aircraft with a reduced fuel load, which moved the cg further forward.

TEST METHODOLOGY

5. Established flight test techniques and data reduction procedures were used for the handling qualities testing (ref 7, app A). All tests were conducted under nonturbulent atmospheric conditions to preclude uncontrolled disturbances from influencing test data. A detailed description of test instrumentation is contained in appendix C. Pilot comments were used to aid in the analysis of data and to determine the overall qualitative assessment of the flying qualities of the OH-58A helicopter with Ministab installed. Performance of the Ministab and the BHC 3-axis systems was also qualitatively compared by the project pilot, who had prior flight experience with the BHC 3-axis SCAS. Test techniques and data analysis methods are described briefly in appendix D, which also includes the Handling Qualities Rating Scale (HQRS) used to augment pilot qualitative comments.

Table 1. Test Conditions.[1]

Type of Test	Gross Weight[2] (lb)	Density Altitude[2] (ft)	Calibrated Trim Airspeed[2] (kt)	Flight Mode
Control positions in trimmed level flight	2800	6800	25 to 105	Level flight[3,4,5]
Static longitudinal stability	2800	6800	50	Level flight[2], climb[3], autorotation[3]
			90	Level flight[3,4,5]
Static lateral-directional stability	2800	6800	90	Level flight[3,5]
Maneuvering stability	2800	6800	90	Level flight[3,4]
Dynamic stability	2800	6800	85	
Long-period				Level flight[5,6]
Short-period				Level flight[3,4,5]
Controllability	2800	2900	Zero	OGE[7] hover[3,4,5]
		6800	90	Level flight[3,4,5]
Autorotational entry	2800	6800	85	Level flight[3]
Mission maneuver	2800	6800	Zero to 90	Level flight[3,5]
		2900		ICE[7] hover[3,5]
Ministab system failures	2800	2900	Zero	OGE hover[3]
		6800	95	Level flight[3]

[1]All flights were flown at a forward cg (107.6 inches).
[2]Aim values.
[3]Ministab ON.
[4]Ministab OFF.
[5]Ministab ON (force trim OFF).
[6]Ministab ON (cyclic OFF).
[7]OGE: Out of ground effect.
ICE: in ground effect.

RESULTS AND DISCUSSION

GENERAL

6. A handling qualities evaluation was conducted to determine the effects on handling qualities of the OH-58A helicopter with Minstab installed. The evaluation revealed significant improvements in the handling qualities as compared to a basic OH-58A helicopter. The most enhancing characteristics provided by Ministab were (1) improved dynamic lateral-directional stability, (2) improved IGE hover characteristics, (3) constant heading capability during ± 10 psi power changes while hovering, (4) improved directional stability during pop-up and bob-up maneuvers, and (5) improved handling qualities during terrain-following. Three shortcomings were noted: (1) excessive directional oscillations during stabilized left sideward flight with Ministab ON at 20 knots true airspeed (KTAS), (2) high roll rate and pitch coupling following a Ministab roll axis hardover, and (3) insufficient aft longitudinal control resulting from a forward hardover in rearward flight. The evaluation was of limited scope and the above observations are accordingly limited. A qualitative comparison between Ministab and the BHC 3-axis SCAS indicated improved stability during maneuvering flight, although a decrease in controllability with Ministab installed was noted. The attitude retention capability incorporated by Ministab, and not available with the BHC SCAS, was qualitatively assessed during precision flight and a decrease in pilot workload was observed.

HANDLING QUALITIES

Control Positions in Trimmed Forward Flight

7. Control positions in trimmed forward flight were determined under the conditions shown in table 1. The tests were conducted with the helicopter trimmed in steady-heading coordinated level flight in 10-knot increments from 24 knots calibrated airspeed (KCAS) to the maximum airspeed for level flight of 104 KCAS. Figure 1, appendix E, presents the results of this test for Ministab ON (force trim ON and OFF) and Ministab OFF flight conditions. Spot checks with Ministab OFF indicate that the control requirements for the basic OH-58A remained essentially unchanged by Ministab operations. As airspeed was increased, increased forward control was required for all conditions tested. The control position characteristics in trimmed forward flight were satisfactory and remained unchanged by Ministab operation.

Static Longitudinal Stability

8. The collective-fixed static longitudinal stability characteristics were evaluated under the conditions shown in table 1. The static longitudinal stability was evidenced by aft displacement of the longitudinal control to maintain slower airspeeds from trim and forward longitudinal displacement to maintain faster

airspeeds from trim. The test results for Ministab ON (force trim ON and OFF) and Ministab OFF are presented in figures 2 and 3, appendix E. The data show that for all conditions tested, the aircraft static longitudinal stability characteristics were stable and independent of Ministab operation. Very little variation in longitudinal stability was noted between level flight and climb, although a near neutral static longitudinal stability was noted in autorotation. This condition was not objectionable and the static longitudinal stability characteristics for the OH-58A helicopter incorporating Ministab are considered satisfactory.

Static Lateral-Directional Stability

9. Static lateral-directional stability characteristics were evaluated under the conditions shown in table 1. Figure 4, appendix E, shows the results of the level flight test with Ministab ON, force trim ON and OFF.

10. The variation of directional control position with sideslip (left pedal for right sideslip) indicated positive directional stability for all conditions tested. There was essentially no difference in the static lateral-directional stability regardless of the Ministab mode tested. Bank angle (roll attitude) gradients were in the proper direction and linear, indicating satisfactory side-force characteristics. Control forces were qualitatively assessed as satisfactory throughout the sideslip envelope. The lateral cyclic control gradient (effective dihedral) decreased in left sideslips and became neutral at sideslip angles greater than 15 degrees (fig. 4, app E). This condition was not considered objectionable and the static lateral-directional stability of the OH-58A helicopter incorporating Ministab is considered satisfactory for all conditions tested.

Maneuvering Stability

11. Maneuvering stability characteristics were evaluated under the conditions shown in table 1. Figure 5, appendix E, shows the results of the evaluation with Ministab ON and OFF.

12. The OH-58A maneuvering stability characteristics, as seen by the variation in longitudinal control position with normal acceleration, were positive (aft control with increasing load factor) for both Ministab ON and Ministab OFF flight conditions. Although the longitudinal control gradient did indicate a more stable condition with Ministab ON (fig. 5, app E), the mode of Ministab operation had essentially no effect on the longitudinal control force gradient. An instability (neutral longitudinal force gradient) was noted at load factors above 1.3 with Ministab ON. This instability caused increased pilot workload to maintain constant airspeed and the desired load factor. However, the increased workload caused by the instability was not considered objectionable. The maneuvering stability characteristics of the OH-58A helicopter incorporating either the BHC or Ministab 3-axis systems indicate the same trends of improving maneuvering stability over the basic OH-58A helicopter. Direct comparison of the Ministab and BHC systems was not possible because of the different test cg and incorporation of a force

trim system with a greater force gradient for the Ministab evaluation. Within the scope of this test, the OH-58A helicopter incorporating the Ministab 3-axis SAS displayed satisfactory maneuvering stability characteristics.

Dynamic Stability

13. The long and short-oeriod longitudinal dynamic stability characteristics, in conjunction with lateral-directional dynamic stability characteristics, were evaluated at the conditions shown in table 1 and the results are presented as time histories in figures 6 through 12, appendix E.

14. The aircraft long-period characteristics were evaluated with the Ministab cyclic mode OFF (directional SAS only) and with attitude retention (force trim) OFF. The results, as shown in figures 6 and 7, appendix E, indicate respective damping ratios (ζ) of 0.166 and 0.128. No abnormal condition was noted with either cyclic SAS or attitude retention disengaged. An attempt to excite the aircraft long-period oscillation with Ministab fully engaged resulted in the aircraft merely assuming a new attitude and maintaining this attitude until the attitude-hold feature was released by pilot control movement or force trim disengagement. The addition of attitude retention, which is not incorporated in the BHC 3-axis SCAS, totally eliminates any aircraft long-period oscillation.

15. The short-period longitudinal gust response characteristics were moderately damped (ζ 0.280) for all conditions tested, as shown in figure 8, appendix E. Light to moderate damping of the short-period oscillations was also noted in the lateral and directional axes (figs. 9 and 10). The short-period longitudinal dynamic characteristics of the OH-58A helicopter with Ministab installed are similar to the longitudinal dynamic characteristics of the OH-58A incorporating the BHC 3-axis SCAS, in that a damping ratio of 0.350 was noted for the BHC SCAS (ref 3, app A). The long and short-period dynamic characteristics for the OH-58A helicopter incorporating the Ministab SAS were satisfactory for all conditions evaluated.

16. The dynamic lateral-directional stability characteristics were tested in level flight under the conditions shown in table 1. Results of these tests are shown in figures 11 and 12, appendix E.

17. The standard OH-58A helicopter with Ministab OFF developed lateral-directional oscillations following a directional control input. These oscillations were moderately damped, as shown in figure 11, appendix E. The same directional control input with Ministab ON resulted in roll oscillations that were heavily damped (fig. 12). The increased damping in the lateral and directional axes improved the dynamic lateral-directional stability and enhanced the aircraft capability when performing mission maneuvers requiring constant-heading flight (HQRS 2). The lateral and directional damping provided by Ministab was similar to damping provided by the BHC SCAS when installed in the OH-58A helicopter. The long and short-period longitudinal dynamic stability characteristics, as well as the lateral and directional dynamic stability characteristics, for the OH-58A helicopter incorporating the Ministab SAS were satisfactory for all conditions tested.

Controllability

18. The aircraft controllability characteristics were evaluated at the conditions shown in table 1. The test techniques and data analysis methods used are described in appendix D. The results of the evaluation are presented in figures 13 through 18, appendix E. Table 2 summarizes MIL-H-8501A compliance and table 3 compares OH-58A controllability with the BHC 3-axis SCAS to the OH-58A incorporating the Ministab SAS.

Table 2. Out-of-Ground-Effect Hover Control Power.[1]

Mode of Flight	Axis	Direction	Ministab		MIL-H-8501A[2]
			ON	OFF	
Hover	Longitudinal	Forward	1.8	1.8	4.7
		Aft	1.8	1.8	4.7
	Lateral	Left	1.5	1.5	2.05
		Right	1.5	1.5	2.05
	Directional	Left	11.5	14.0	7.05
		Right	6.0	12.5	7.05
Level (90 KCAS)	Longitudinal	Forward	1.2	1.9	NA
		Aft	1.8	2.8	
	Lateral	Left	1.5	2.3	
		Right	1.5	2.2	
	Directional	Left	4.0	10.0	
		Right	6.0	11.0	

[1]Control power: Pitch or yaw angular displacement (in degrees) at 1 second resulting from 1-inch longitudinal or directional control step input, respectively.
Roll angular displacement (in degrees) at 1/2 second resulting from 1-inch lateral control step input.
[2]Minimum values required by para 3.6.1.1.
2800 pounds gross weight was used to calculate compliance.

Table 3. Out-of-Ground-Effect Hover Controllability Comparison.

Axis	Test[1]	Direction	Hover		Level Flight	
			BHC SCAS ON[2]	Ministab SAS ON[3]	BHC SCAS ON[4]	Ministab SAS ON[5]
Longitudinal	Control power	Forward	3.4	1.8	2.3	2.0
		Aft	3.7	1.8	2.5	2.0
	Control response	Forward	6.2	4.0	3.5	2.0
		Aft	6.8	4.0	4.5	4.0
	Control sensitivity	Forward	10.0	4.0	8.0	4.0
		Aft	11.2	4.0	8.3	4.0
Lateral	Control power	Left	2.5	1.5	6.3	1.5
		Right	2.0	1.5	2.0	1.5
	Control response	Left	6.0	6.0	7.0	6.0
		Right	9.3	6.0	10.2	6.0
	Control sensitivity	Left	24.0	12.0	28.0	12.0
		Right	24.0	12.0	28.0	12.0
Directional	Control power	Left	19.8	11.5	10.3	4.0
		Right	19.5	6.0	14.0	6.0
	Control response	Left	26.0	20.0	15.0	7.5
		Right	21.0	16.0	23.5	10.5
	Control sensitivity	Left	51.0	25.0	45.0	12.5
		Right	46.0	17.5	52.0	22.5

[1]Units:
Control power: Lateral = deg/in. at 1/2 second.
Longitudinal/directional = deg/in. at 1 second.
Control response: Deg/sec/in.
Control sensitivity: deg/sec^2/in.
Average conditions:
[2]Density altitude: 2200 ft; gross weight: 2795 lb; cg: aft (111.4 in.).
[3]Density altitude: 3050 ft; gross weight: 2770 lb; cg: fwd (107.5 in.).
[4]Density altitude: 5880 ft; gross weight: 2730 lb; cg: aft (111.5 in.).
[5]Density altitude: 6740 ft; gross weight: 2820 lb; cg: fwd (107.7 in.).

19. In a hover, the aircraft control response and sensitivity with Ministab ON was less than for the basic OH-58A (figs. 13 through 15, app E), although aircraft longitudinal and lateral control power appeared to be independent of Ministab operation. Table 2 compares test values for aircraft control power and shows that the lateral and longitudinal control power does not meet the minimum requirements of paragraph 3.6.1.1 of MIL-H-8501A. Directional control power to the right with SAS ON also failed to comply with paragraph 3.6.1.1. Although the requirements of paragraph 3.6.1.1 were not met, the controllability characteristics of the OH-58A helicopter incorporating the Ministab SAS were considered satisfactory.

20. During level flight the basic aircraft control power, response, and sensitivity was reduced with Ministab fully engaged (figs. 16 through 18, app E). A summary of the results may be found in table 2. Differences between aircraft controllability in level flight with Ministab fully engaged and with force trim OFF (attitude retention disengaged) were not present, due to the fact that flight control inputs made by the pilot activate a programmed cutoff in the integration circuit which prevents attitude retention during maneuvers. Table 3 is a comparison of control power, response, and sensitivity between the OH-58A helicopter incorporating the BHC 3-axis SCAS (ref 3, app A) and the OH-58A with Ministab installed. Aircraft controllability appears to be less with Ministab than with the BHC 3-axis SCAS. This reduction in aircraft controllability was not noticeable to the pilot, and was not considered detrimental to the aircraft flying qualities.

Autorotational Entry

21. The autorotational entry characteristics of the Ministab-equipped OH-58A helicopter were evaluated from level flight at the conditions shown in table 1. A representative time history is shown in figure 19, appendix E. The initial reaction of the helicopter to sudden power loss was characterized by left yaw and near-constant roll and pitch attitudes. The damping provided by Ministab was noticeable and reduced the yaw rate experienced, significantly reducing the pilot effort required during recovery (HQRS 3). Recovery from the simulated engine failure in all cases was necessary when the main rotor speed decreased below the minimum rotor speed, rather than by excessive changes in helicopter attitudes. Within the scope of this test, the autorotational entry characteristics of the Ministab-equipped OH-58A helicopter are satisfactory.

Mission Maneuvers

Hovering Characteristics:

22. The capability of the OH-58A helicopter with Ministab installed to hover IGE and OGE was qualitatively evaluated at the conditions shown in table 1. The helicopter was hovered over a fixed ground reference with Ministab ON, and with Ministab ON and force trim OFF.

23. Hovering IGE and OGE over a fixed ground reference, with Ministab ON, was characterized by near-constant roll and pitch attitude, requiring only small attitude changes to stop translation of the helicopter. The cyclic control inputs required to make these attitude changes were small, requiring minimal pilot compensation (HQRS 3). Cyclic control-free hovering (hands-off) could be accomplished by proper trimming; however, wind effects could not be compensated for to prevent translation from the ground reference point. This technique was used only to demonstrate the stability provided by the Ministab SAS and has no operational value. Longitudinal cyclic control movements with Ministab operational were not required for collective inputs resulting in less than ±10-psi (±9 percent) engine torque changes. However, increased longitudinal cyclic control inputs were required to correct pitch attitude changes resulting from collective inputs producing greater than ±10-psi engine torque changes. These longitudinal cyclic control inputs were not objectionable. In summary, the OH-58A helicopter precision hovering characteristics were enhanced by the addition of Ministab.

24. The helicopter heading was established by pilot directional control inputs. Once the desired heading was established, further directional control inputs were not required to maintain the desired heading during constant-altitude hover (HQRS 2). There was no noticeable heading change with the cyclic and collective control inputs required to maintain constant IGE or OGE hover altitude. Collective control inputs resulting in ±10-psi engine torque changes, with no corrective directional control inputs, caused heading deviations of ±3 degrees from the trim heading. The heading deviation could easily be prevented when directional control inputs were applied, even though engine torque changes were greater than 10 psi. The capability of Ministab to hold heading within ±3 degrees with power changes of ±10-psi (±9 percent) engine torque is an enhancing feature.

25. Constant-altitude, left and right 360-degree directional turns were accomplished in IGE hover over a fixed ground reference. Minimal pitch and roll attitude corrections were required during execution of the turn (HQRS 3). Establishing the desired turn rate required directional control input in the desired direction of turn and minimal pilot compensation to maintain the turn rate (HQRS 3). The attitude retention capability incorporated by Ministab, and not available with the BHC SCAS, improved the hovering characteristics of the OH-58A helicopter and a decrease in pilot workload was observed. Within the scope of this test, the hovering characteristics of the OH-58A helicopter with Ministab ON are satisfactory.

26. The eff[illegible] of Ministab ON, force trim OFF, was to change the stability augmentatio[illegible] the helicopter from rate damping with attitude retention to rate damping only (app B). This change was very noticeable and required the pilot to change his control technique from commanding attitudes to controlling rates. Hovering with the force trim OFF was characterized by the requirement to make small attitude corrections for external disturbances and for maintaining a constant position over a ground reference. Pilot concentration was increased in all axes and required moderate pilot compensation by increasing control activity (HQRS 4). Increased cyclic control movements were not noticed for the small collective

movements required to maintain constant altitude. However, for collective movements producing greater than ±10-psi engine torque changes, pitch rates would develop requiring longitudinal cyclic corrective inputs. This characteristic was not objectionable. The characteristics noted above were qualitatively assessed by the pilot to be essentially the same as for previous tests with a BHC SCAS installed.

27. Hovering (IGE) turns (left and right, 360 degrees) over a fixed ground reference with Ministab ON and force trim OFF were characterized by near-constant pitch and roll attitudes. A turn rate was established by a directional control input in the required direction and no further pilot compensation was required to maintain the resultant turn rate (HQRS 2). Within the scope of this test, the hovering characteristics of the OH-58A helicopter with Ministab ON, force trim OFF, are satisfactory.

Lateral Acceleration:

28. The lateral acceleration characteristics of the OH-58A helicopter with Ministab installed were qualitatively evaluated at the conditions shown in table 1. The testing was conducted with Ministab ON. Accelerated flight from a hover to the left was smooth and required only small control inputs. However, as the helicopter reached approximately 20 to 25 KTAS in left sideward flight, abnormally high vibration levels were qualitatively assessed and increasing directional oscillations occurred. The directional oscillations occurring in left sideward flight do not comply with paragraph 3.3.2 of MIL-H-8501A. The helicopter was apparently limited in accelerated flight to the left by the inability of the Ministab to aid the pilot in correcting the directional oscillations at these airspeeds. (The oscillations in this flight condition are characteristic of the basic OH-58A helicopter.) The directional control inputs required extensive pilot compensation to control the directional oscillations (HQRS 6). Accelerated flight from a hover to the right was accomplished up to the 35-KTAS sideward airspeed limit of the helicopter. The helicopter vibrations remained normal and there was no tendency toward directional oscillations during transition to the sideward airspeed limit. The complete right sideward acceleration maneuver required minimal pilot compensation to control the helicopter (HQRS 3). Within the scope of this test, the excessive helicopter directional oscillation with Ministab ON at 20 KTAS in left sideward flight is a shortcoming. This condition was degraded by disengagement of Ministab.

Vertical Displacement:

29. Vertical displacement maneuvers in the Ministab-equipped OH-58A helicopter were conducted from a hover and in forward flight. The two maneuvers evaluated were the bob-up (hover) and pop-up (forward flight). The characteristics of the helicopter were qualitatively evaluated with Ministab ON.

30. The hovering characteristics for both IGE and OGE hover are described in paragraph 23 of this report. The transition from stabilized IGE hover to maximum takeoff power vertical climb (bob-up) was easily accomplished. Minimal directional

control inputs were required to correct for the power increase (HQRS 3). Throughout the climb, the pitch and roll attitude remained essentially constant. Transition to the OGE hover required minimal control inputs in all axes to establish the hover (HQRS 3). The ease of transition to vertical descent and the vertical descent characteristics were essentially the same as the climb portion.

31. The constant-airspeed pop-up maneuver was characterized by essentially constant attitudes throughout its execution. The maneuver was easily accomplished, requiring minimal corrective control inputs in the roll, pitch, and directional axes for the large power changes required to perform the vertical displacement (HQRS 3). The improved level of stability provided to the OH-58A helicopter by the Ministab SAS decreases pilot workload throughout the bob-up and pop-up maneuvers and is an enhancing characteristic.

Terrain Following:

32. The terrain-following flight characteristics of the Ministab-equipped OH-58A helicopter were qualitatively evaluated over rolling desert-type terrain. The helicopter was flown at an essentially constant altitude (50 feet above ground level) and at airspeeds of 50 to 90 knots indicated airspeed (KIAS). The Ministab SAS was ON during the evaluation. The helicopter was stable in all axes and minimal corrective control inputs were required for engine torque changes from 30 to 70 psi. Specifically, as the necessary power changes were made, minimal pilot compensation was required to correct for collective to pitch axis coupling (HQRS 3). In addition, these large power changes required minimal directional control corrections by the pilot, such as are required in an unaugmented OH-58A helicopter (HQRS 3). During constant-altitude and airspeed flight, the attitude retention capability of Ministab, which is not available in the BHC SCAS, decreased the pilot workload by reducing flight control activity. Within the scope of this test, the stability augmentation provided by Ministab enhanced the terrain-following capability of the OH-58A helicopter.

Ministab Stability Augmentation System Failures

33. A limited evaluation was conducted to determine flight characteristics during forward, rearward, and hovering flight following a Ministab SAS failure. The OH-58A helicopter incorporates mixing of the lateral and longitudinal controls, which generates simultaneous lateral and longitudinal servo movement from pure longitudinal control movement. As a result, longitudinal SAS failures generate both lateral and longitudinal servo movement, although the aircraft experiences longitudinal response only (figs. 20 and 24, app E). Test conditions are shown in table 1 and test results in figures 20 through 27.

Forward Flight:

34. Forward flight SAS hardover tests were conducted during coordinated level flight and climbing flight (500 feet per minute). Helicopter reactions to longitudinal hardovers were mild for both flight conditions. The pitch hardover (forward and

aft) was characterized by the helicopter obtaining a new attitude with no coupling in the other axes (fig. 20, app E). Yaw axis hardovers were similarly mild and characterized by the helicopter increasing sideslip angle approximately 14 degrees opposite to the failure and with very little pitch or roll coupling (fig. 21). Recovery from the pitch or yaw hardovers required the pilot to apply an opposite corrective control input or disengage the affected SAS control (HQRS 4). Delays greater than 3 seconds were possible before corrective action was necessary following a pitch yaw axis hardover. Within the scope of this test, the Ministab SAS failure characteristics in the pitch and yaw axes in forward flight are satisfactory.

35. Roll axis SAS hardovers in forward flight were characterized by an excessive roll rate in the direction of the hardover (figs. 22 and 23, app E). Additionally, pitch axis coupling was present with nose-down pitching associated with left roll hardovers and nose-up pitching with right roll hardovers. High roll rates combined with the pitch coupling required immediate corrective action to prevent an unusual attitude. This characteristic is unsatisfactory and would seriously degrade the capability of the Ministab-equipped OH-58A helicopter to safely operate in instrument meteorological conditions. Within the scope of this test, high roll rate combined with pitch coupling associated with Ministab roll axis hardovers is a shortcoming.

Rearward Flight:

36. Limited Ministab hardover tests in rearward flight were conducted in the pitch axis only (nose down). The results of USAASTA Project No. 72-20 indicated that it could be possible to reach an aft longitudinal control limit if a forward hardover were to occur with a forward cg and when hovering downwind in winds exceeding 15 knots, with a SAS having 10-percent actuator authority. The same report indicates that the basic OH-58 helicopter has 5 percent longitudinal control remaining at 30 knots rearward flight. Forward hardover tests with the Ministab at rearward airspeeds of 15 to 20 KTAS resulted in insufficient longitudinal control to correct for the nose-down pitch attitude. The requirements of paragraph 3.2.1 of MIL-H-8501A were not met, in that a 10-percent control margin was not available in 30-knot (KTAS) rearward flight. Within the scope of this test, insufficient aft longitudinal control resulting from a forward Ministab SAS hardover in rearward flight is a shortcoming. The following CAUTION should be placed in the operator's manual if OH-58A helicopters are equipped with the Ministab SAS.

CAUTION

Hovering downwind with Ministab ON in winds in excess of 15 knots should be avoided with a forward cg. Insufficient aft longitudinal control will be available if a forward longitudinal SAS hardover occurs.

Hovering Flight:

37. Hovering flight SAS hardover tests were conducted in the pitch, yaw, and roll axes and results are shown in figures 24 through 27, appendix E. Attitudes and/or rates resulting from individual SAS hardovers were easily recognizable and were not excessive. Recovery from the SAS hardovers during hover required only that the pilot apply an opposite corrective control input or disengage the SAS (HQRS 4). The helicopter exhibited no coupling of nonfailed axes with the axis experiencing the hardover. Within the scope of this test, the Ministab SAS failure characteristics in hovering flight are satisfactory.

CONCLUSIONS

GENERAL

38. The following conclusions were reached upon completion of the Ministab SAS evaluation:

a. Within the scope of this evaluation, the handling qualities of the basic OH-58A helicopter are greatly improved with Ministab installed.

b. The enhancing characteristics provided by Ministab were as follows:

(1) Improved dynamic lateral-directional stability (para 17).

(2) Improved precision hover characteristics (para 23).

(3) Heading-hold capability within ±3 degrees during ±10-psi (±9 percent) power changes in IGE and OGE hover (para 24).

(4) Improved stability and reduced pilot workload during pop-up and bob-up maneuvers (para 31).

(5) Improved control and reduced pilot workload during terrain-following (para 32).

c. Comparison between the Ministab SAS and the BHC SCAS showed the following:

(1) The maneuvering stability characteristics of the OH-58A helicopter incorporating either system indicate the same trends of improving maneuvering stability over the basic OH-58A helicopter (para 12).

(2) The addition of attitude retention, which is not incorporated in the BHC 3-axis SCAS, totally eliminates any aircraft long-period oscillation (para 14).

(3) The short-period longitudinal dynamic characteristics of the OH-58A helicopter were similar with either system installed (para 15).

(4) The lateral and directional damping provided by Ministab was similar to damping provided by the BHC SCAS (para 17).

(5) Aircraft controllability appears to be less with Ministab than with the BHC SCAS (para 20).

(6) With the force trim OFF, hovering characteristics with the Ministab and BHC systems were qualitatively assessed to be essentially the same (para 26).

d. Three shortcomings were identified.

SHORTCOMINGS

39. The following shortcomings were identified:

a. Excessive directional oscillations at 20 KTAS in left sideward flight with Ministab ON (para 28).

b. High roll rate combined with pitch coupling following a Ministab roll axis hardover at 95-KCAS forward flight (para 35).

c. Insufficient aft longitudinal control resulting from a forward hardover in rearward flight (para 37).

SPECIFICATION COMPLIANCE

40. Within the scope of this test, the stability and control characteristics of the OH-58A helicopter with the Ministab 3-axis SAS installed failed to meet the following requirements of MIL-H-8501A:

a. Paragraph 3.6.1.1 - Less than specified longitudinal and lateral control power in a hover (para 19).

b. Paragraph 3.6.1.1 - Less than specified right directional control power in a hover with SAS ON (para 19).

c. Paragraph 3.3.2 - Excessive directional oscillations in 25-knot left sideward flight (para 28).

d. Paragraph 3.2.1 - Inadequate aft longitudinal control remaining during 30-knot rearward flight (para 36).

RECOMMENDATIONS

41. If future consideration is given to operational use of the SFENA Ministab SAS, the identified shortcomings should be corrected.

42. The following CAUTION should be placed in the operator's manual for OH-58A helicopters equipped with the Ministab SAS (para 36).

CAUTION

> Hovering downwind with Ministab ON in winds in excess of 15 knots should be avoided with a forward cg. There will be insufficient aft longitudinal control if a forward longitudinal SAS hardover occurs.

APPENDIX A. REFERENCES

1. Letter, AVSCOM, AMSAV-EFT, 9 November 1973, subject: Test Directive, Ministab Evaluation, Project No. 74-23.

2. Military Specification, MIL-H-8501A, *Helicopter Flying and Ground Handling Qualities; General Requirements For*, 7 September 1961, amended 3 April 1962.

3. Final Report, USAASTA, Project No. 72-20, *Handling Qualities Evaluation of the OH-58A Helicopter Incorporating the Model 570B Three-Axis Stability and Control Augmentation System*, February 1973.

4. Technical Manual, TM 55-1520-220-10, *Operator's Manual, Army Model OH-58A Helicopter*, 13 October 1970.

5. Message, AVSCOM, AMSAV-EFT, 061300Z March 1974, subject: Safety of Flight Release, USAAEFA Project No. 74-23.

6. Flight Test Manual, Naval Air Test Center, FTM No. 101, *Helicopter Stability and Control*, 10 June 1968.

APPENDIX B. MINISTAB DESCRIPTION

GENERAL

1. The standard configuration OH-58A helicopter was modified by adding a boosted tail rotor system and a 3-axis Ministab system manufactured by the Societe Francaise d'Equipements pour la Navigation Aerienne (SFENA) of France. The system consists of a control panel, three interchangeable electrohydraulic actuators, three interchangeable computers, and three control motion transducers. The three electrohydraulic actuators are interchangeable in that the mechanical travel of each may be adjusted to meet the manufacturer's specifications. The interchangeability of the system computers is provided by calibrations peculiar to each actuator of the three control channels, the appropriate calibration being determined by the wiring of the related connector for a given channel. The major components are shown in figure 1 and a block diagram is shown as figure 2.

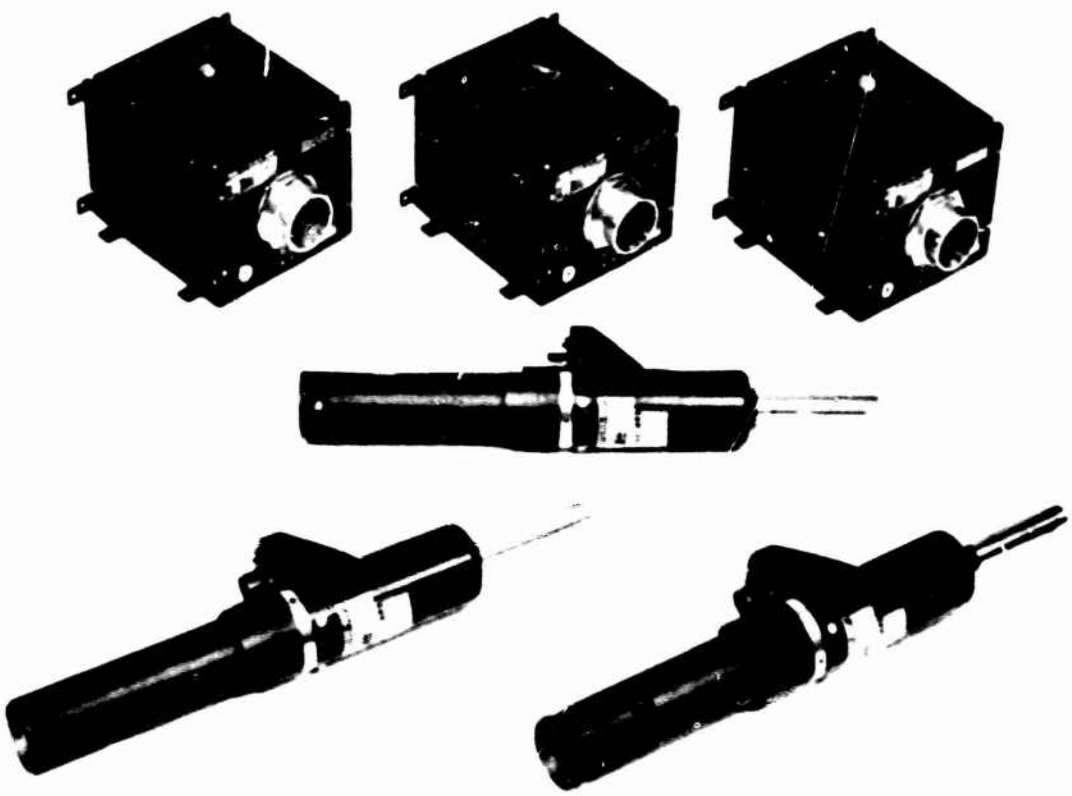


Figure 1. Ministab Major Components.

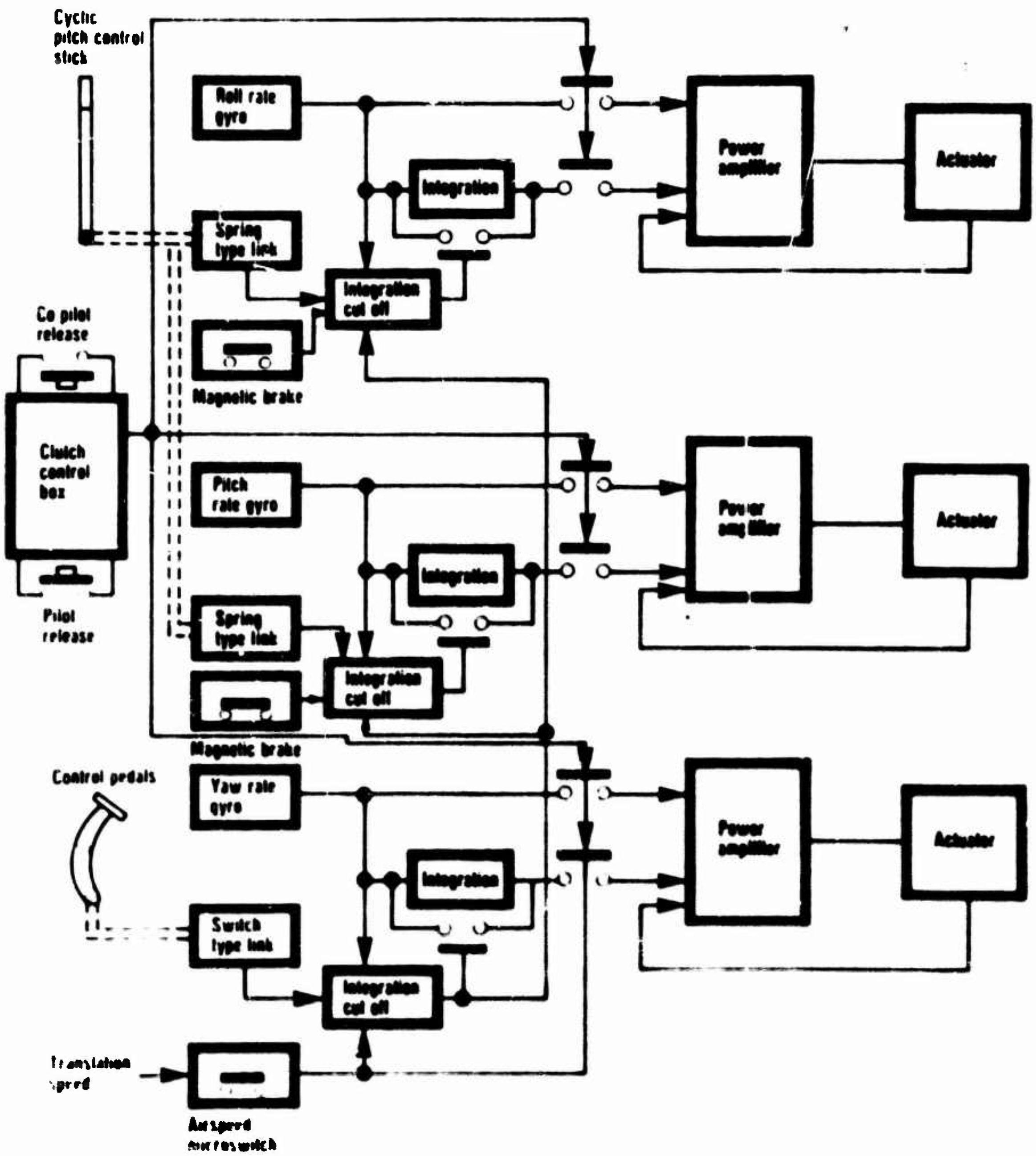


Figure 2. Ministab Block Diagram.

CONTROL PANEL

2. The control panel contains a power switch for applying primary power to the system and two secondary switches for engagement or disengagement of the cylic (longitudinal and lateral) and yaw channels. Ministab engagement is indicated by an illuminated control panel and by primary control switch position. The secondary switches enable the selection of two-channel cyclic mode operation or single-channel (directional) mode operation.

ELECTROHYDRAULIC ACTUATORS

3. There are three limited-authority electrohydraulic series-type actuators installed on the flight control linkages. The authority of each actuator is limited to approximately ±10 percent of the total pilot control authority. To provide a positive safety feature, the actuators are self-centering by built-in springs which mechanically move the actuator to the center position in the event of electrical or hydraulic power failure. This feature also lessens cyclic and directional stick bump during system engagement and disengagement.

CONTROL MOTION TRANSDUCERS

4. The control motion transducers are installed on the pitch, roll, and yaw axes of the pilot's flight controls. These motion transducers measure physical movement of the flight controls in each axis and provide an electrical signal to respective system computers which cut out the integration circuit or attitude hold, degrading the system to a rate-sensitive system. A 2-percent flight control movement of the longitudinal, lateral, or directional controls cuts out this integration circuitry, thus allowing the SAS to distinguish displacements of the airframe that result from pilot maneuvering commands from those caused by external disturbances. The attitude-hold feature is also cut out of the loop when force trim is disengaged.

SYSTEM OPERATION

5. The three similarly constructed channels (pitch, roll, and yaw) are actuated by an electrical signal issued from three respective rate gyros. The resultant signal, which is interpreted by one of the three system computers, forms an angular-rate term, in conjunction with an attitude term (angular-rate integration). These terms are amplified by a power amplifier and signaled to electrohydraulic actuators which are placed in series with the primary control servos. The primary control servos, which receive the final combined inputs from Ministab and the flight controls, transfer these commands to the control surfaces. Because the attitude-hold feature would tend to lessen aircraft control power, three control motion transducers, sensitive to any control motion exceeding 2-percent total control travel, are incorporated to cut off integration (attitude hold). The integration cut-off is maintained until the rate term for the respective axes falls below 1.5 degrees per second.

APPENDIX C. INSTRUMENTATION

Sensitive instrumentation was installed and maintained by the Data Systems Office of USAAEFA. The following parameters were recorded:

<u>Pilot and Engineer Panels</u>

Airspeed (boom)
Altitude (boom)
Angle of sideslip
Rotor speed (sensitive)
Center-of-gravity normal acceleration
Free air temperature
Longitudinal control position
Lateral control position
Directional control position
Collective control position
Total fuel used
Magnetic tape record counter
Event record counter

<u>Magnetic Tape Recorder</u>

Longitudinal control position
Lateral control position
Directional control position
Collective control position
Longitudinal control force
Lateral control force
Directional control force
Pitch attitude
Roll attitude
Yaw attitude
Pitch rate
Roll rate
Yaw rate
Altitude (boom)
Airspeed (boom)
Free air temperature
Angle of sideslip
Center-of-gravity normal acceleration
Rotor speed
Stability augmentation system positions (3)
Throttle position

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

1. The control positions in forward level flight were determined by trimming the aircraft (ball-centered) at selected airspeeds and recording the control position requirements. The results were used to establish compliance with MIL-H-8501A.

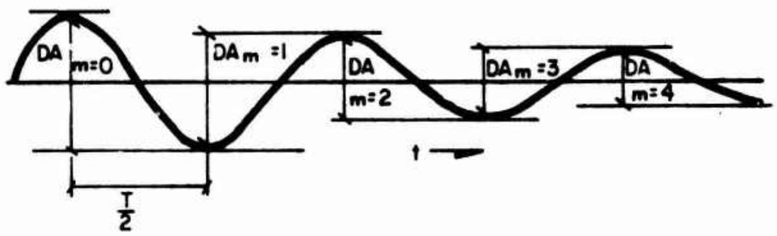
2. The collective-fixed static longitudinal stability characteristics were evaluated by trimming the aircraft (ball-centered) in steady-heading level flight. Without changing the collective control or power setting, the aircraft was then stabilized at incremental airspeeds greater and less than trim airspeed, using longitudinal control only. The results of this test were used to establish longitudinal control and force gradients with forward airspeed. The test results were checked for compliance with MIL-H-8501A.

3. The static lateral-directional stability characteristics were evaluated by trimming the aircraft to zero sideslip flight at the desired airspeed and recording the control positions and roll attitude. Holding collective fixed, the aircraft was then displaced to incremental sideslip angles on either side of trim and stabilized in a steady-heading sideslip. The control positions and roll attitudes were recorded at increasing sideslip angles up to the sideslip limit. The static lateral-directional tests were used to determine the aircraft side-force characteristics, effective dihedral and directional stability, and to verify compliance for each with MIL-H-8501A.

4. Maneuvering stability characteristics were evaluated to determine the flying qualities with SAS activated during maneuvering flight. The test was conducted by trimming the aircraft in coordinated level flight at the desired airspeed and performing windup turns, increasing the bank angle to achieve the aim normal acceleration or g loading. The collective control was held fixed at the level flight trim setting and the trim airspeed was maintained by allowing the aircraft to descend, as necessary. The tests were conducted to the left with SAS ON and OFF. The normal acceleration and longitudinal control force and position were recorded to document maneuvering stability characteristics.

5. The longitudinal dynamic stability characteristics were evaluated to establish long and short-term response characteristics. To evaluate the long-term response characteristics, the aircraft was stabilized at a trim airspeed and then displaced either faster or slower by desired increments, using longitudinal cyclic control only. The controls were then returned to the original trim position and held rigidly with a control fixture while helicopter response was recorded. Gust response or short-period response characteristics were investigated by applying 1-inch longitudinal control pulses both forward and aft for 1/2 second. Aircraft damping during the long-period oscillations was derived using transient peak ratios, which are related to the damping ratio by the following formula:

$$\zeta = \left[\frac{1}{1 + \left[\frac{-(m_r - m_o)\pi}{\ln(TPR)} \right]^2} \right]^{1/2}$$



Where:

m_r - m_o = Number of consecutive peaks (double amplitude)

TPR = Transient peak ratio $\left[\frac{DA_m = r}{DA_m = o} \right]$

The short-period dynamic lateral-directional characteristics were evaluated by applying lateral-directional inputs independently in both directions for approximately 1/2 second.

6. The Dutch-roll characteristics or lateral-directional dynamic stability were evaluated by executing a directional doublet and returning to trim. The results were analyzed to determine the dynamic lateral-directional characteristics.

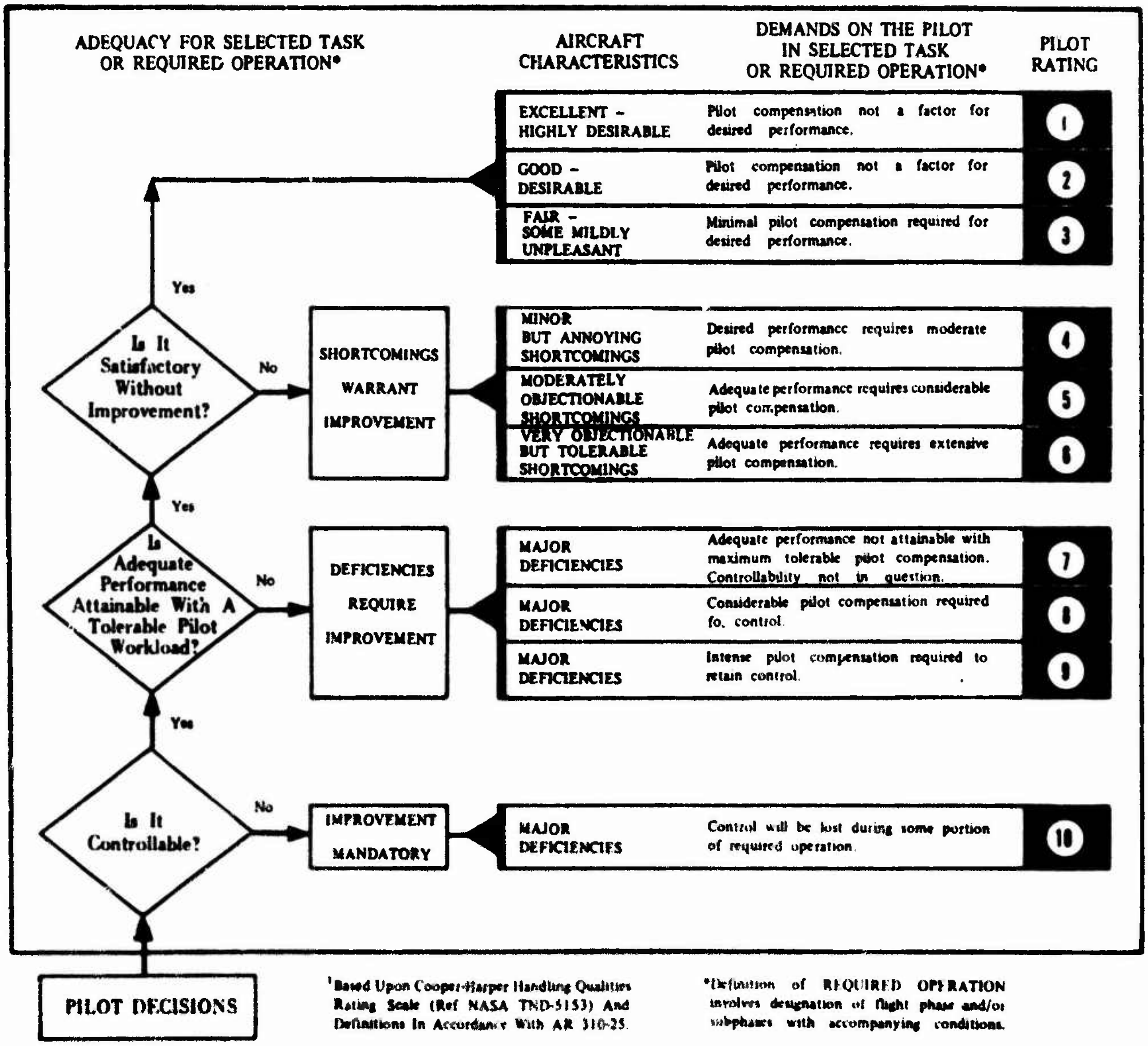
7. Aircraft controllability tests were conducted by applying single-axis step inputs to the longitudinal, lateral, and directional controls, using a mechanical fixture to obtain the desired control displacements. The step inputs were held steady until maximum aircraft angular rate (control response) was recorded. The aircraft maximum angular acceleration (control sensitivity) was mathematically derived from the angular rate data. Two step inputs of increasing displacement in each direction were applied to each axis to establish controllability trends. The control power and damping characteristics during OGE hover were checked for compliance with the requirements of MIL-H-8501A.

8. The autorotational entry or engine failure characteristics were simulated by rapidly retarding the throttle to the flight-idle position and holding all flight controls fixed for 2 seconds, or until recovery was required. The tests were conducted with Ministab ON.

9. The lateral acceleration characteristics were investigated by first stabilizing aircraft attitudes and power in a hover and then laterally accelerating (left and right) by incrementally increasing bank angle and adjusting power as required, until a vibration or control limit was reached.

10. The vertical displacement maneuvers consisted of bob-up and pop-up maneuvers. The bob-up maneuver was conducted by performing a rapid takeoff power vertical climb from a 5-foot hover to approximately 200 feet above ground level (AGL), stabilizing in an OGE hover, and returning vertically to the 5-foot hover. The pop-up maneuver was a rapid vertical displacement from approximately 50 feet AGL and 40 to 50 KIAS (forward airspeed) to approximately 200 feet AGL, stabilizing, and returning to the original altitude.

11. Ministab SAS hardovers were performed by using an electronic box equipped with switches and dials for controlling duration and intensity of the simulated SAS hardovers. Results of the test determined aircraft reactions to system failure and requirements for recovery action.



[1]Based Upon Cooper-Harper Handling Qualities Rating Scale (Ref NASA TND-5153) And Definitions In Accordance With AR 310-25.

*Definition of REQUIRED OPERATION involves designation of flight phase and/or subphases with accompanying conditions.

Figure 1. Handling Qualities Rating Scale.

APPENDIX E. TEST DATA

INDEX

FIGURE 1

CONTROL POSITIONS IN TRIMMED LEVEL FLIGHT

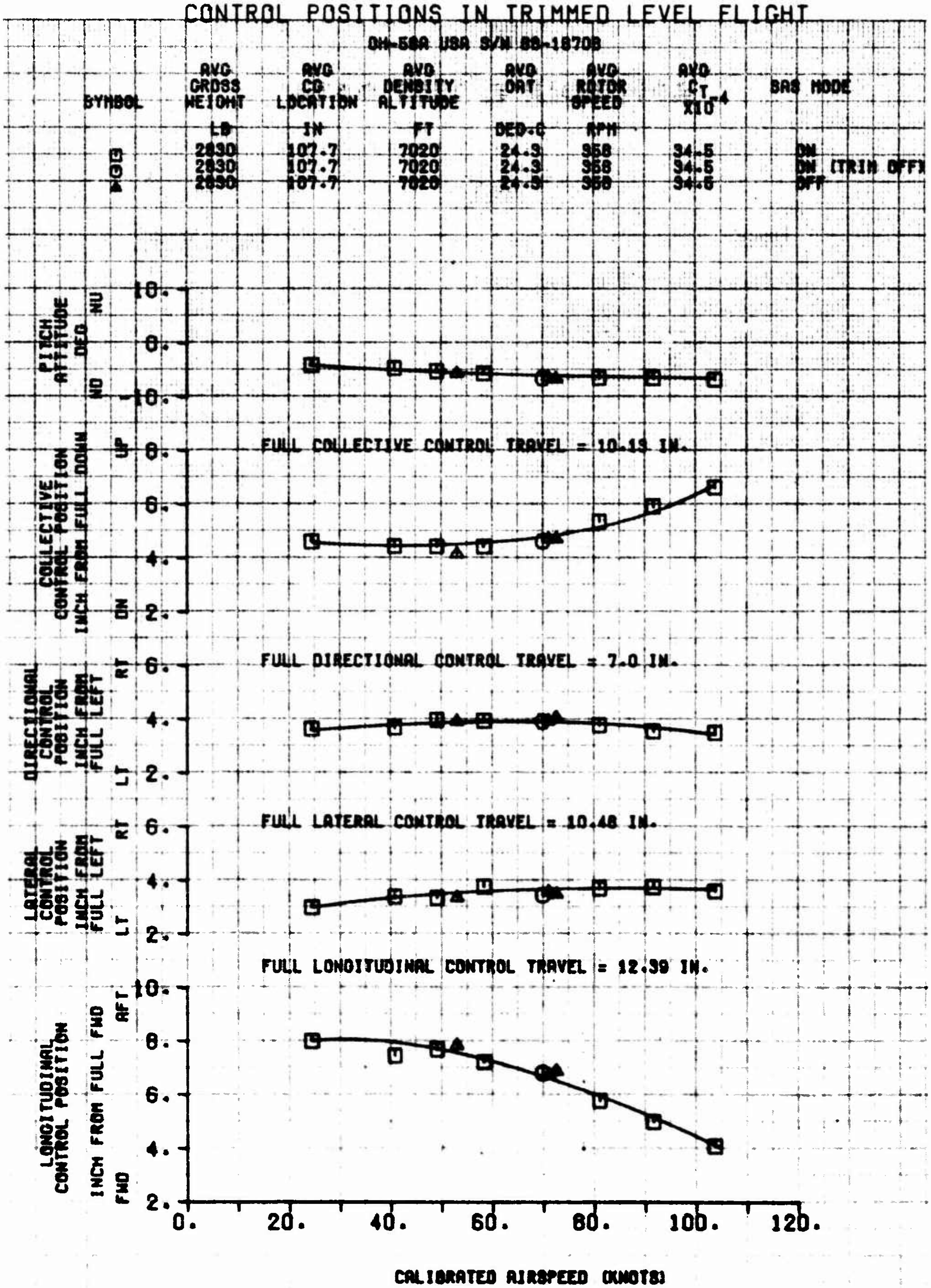


FIGURE 2

STATIC LONGITUDINAL STABILITY

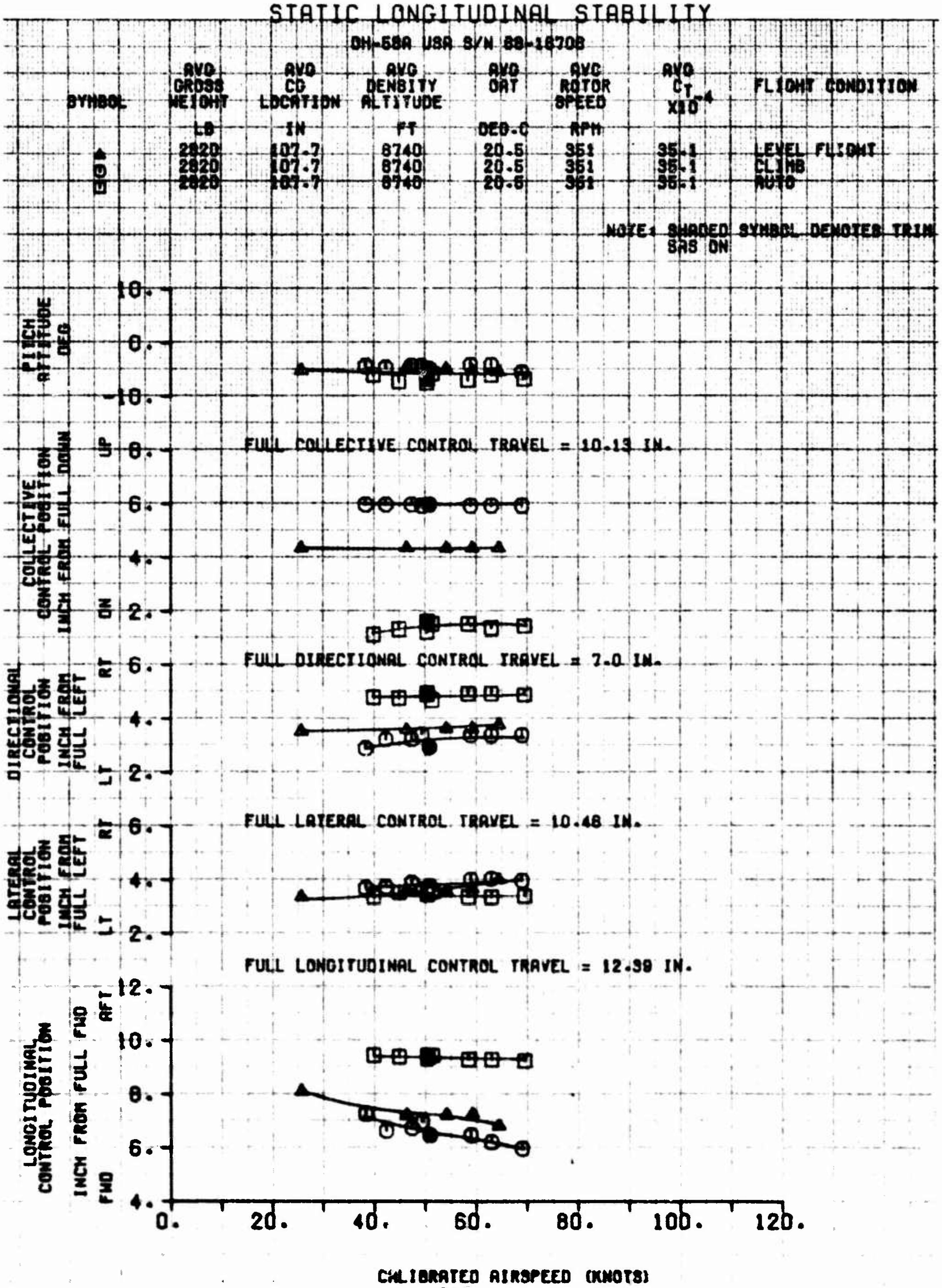


FIGURE 3
STATIC LONGITUDINAL STABILITY

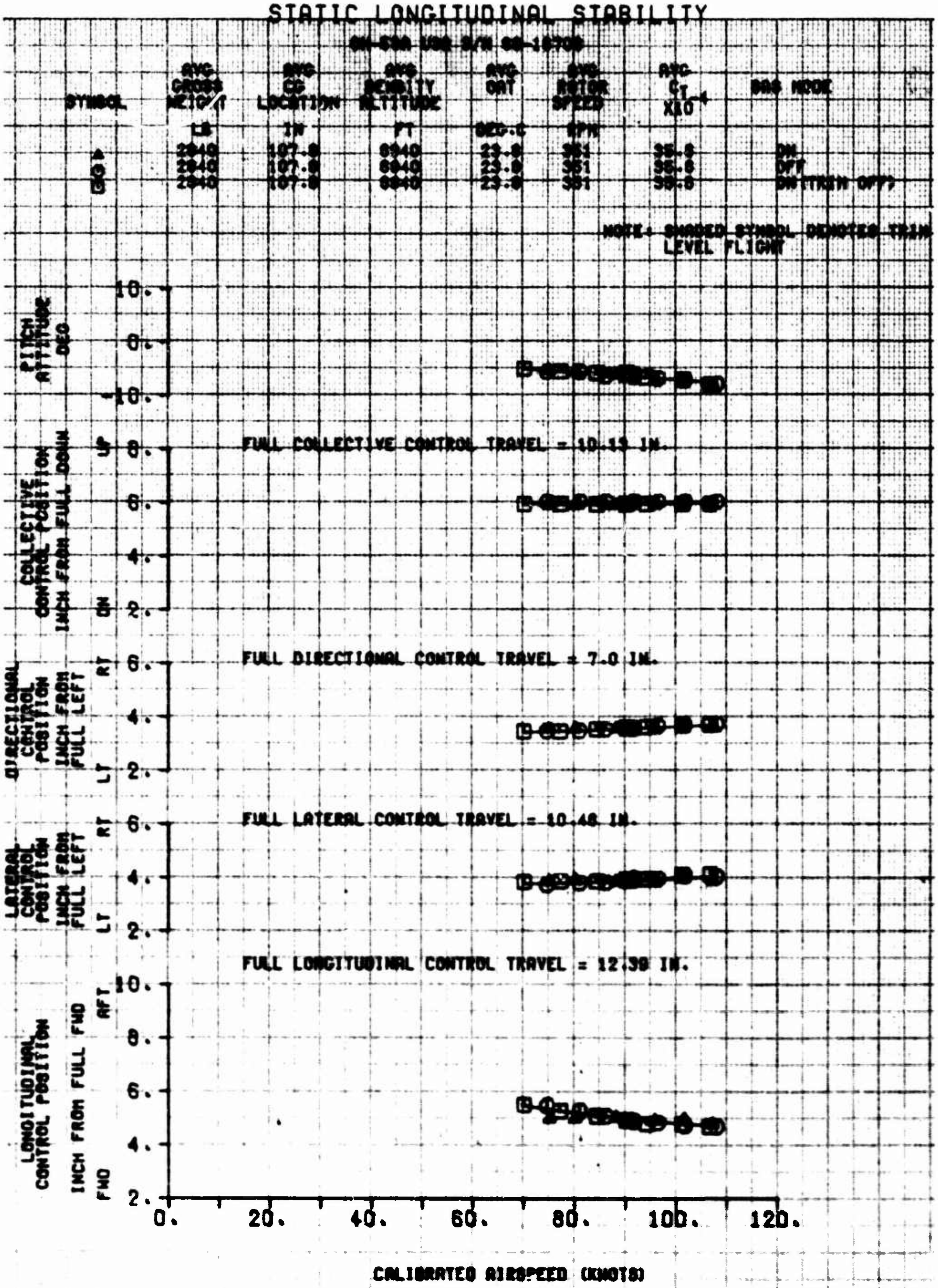


FIGURE 4

STATIC LATERAL - DIRECTIONAL STABILITY IN LEVEL FLIGHT

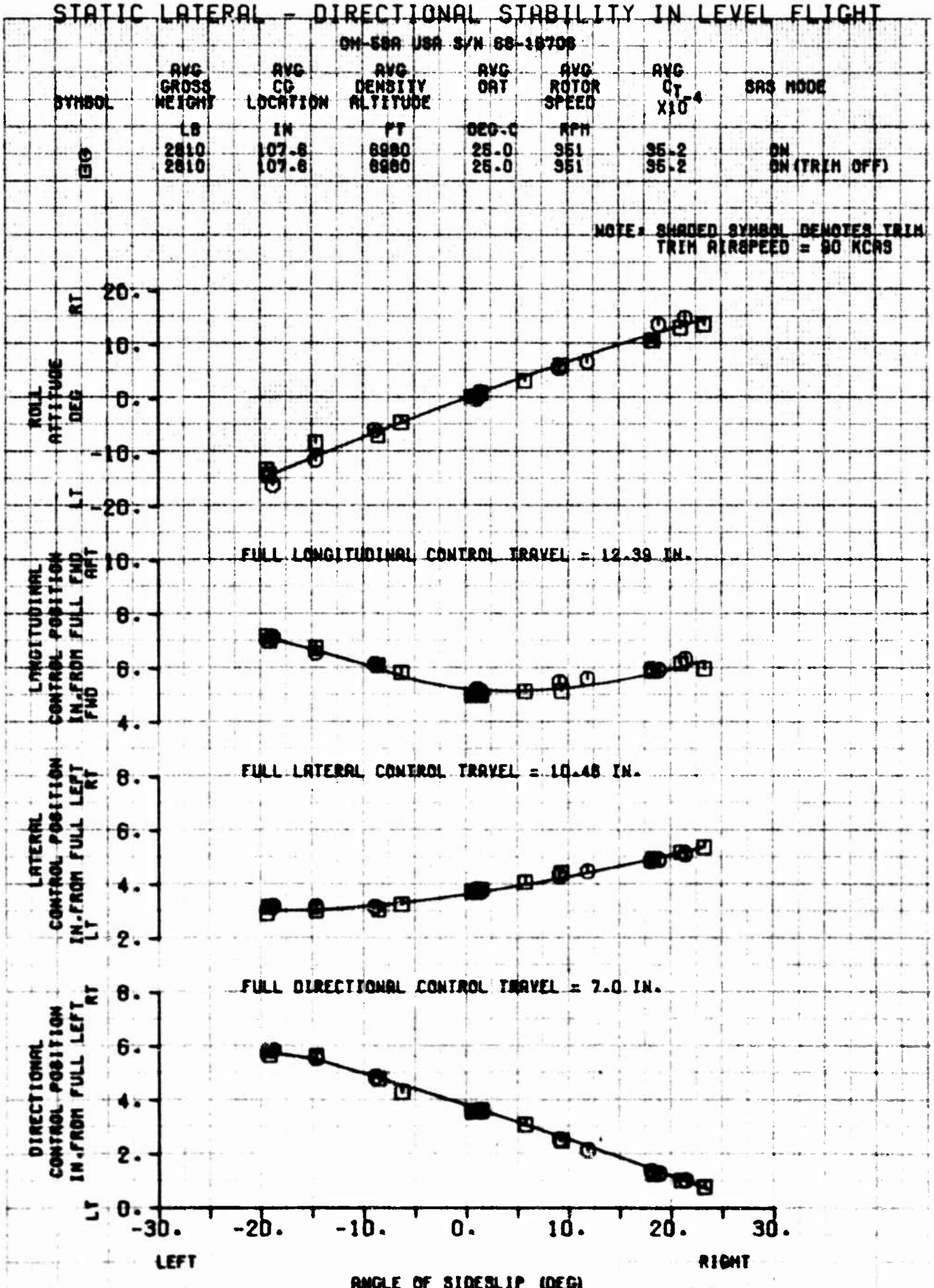


FIGURE 5
MANEUVERING STABILITY
OH-58A USA S/N 68-16706

SYMBOL	AVG GROSS WEIGHT LB	AVG CG LOCATION IN	AVG DENSITY ALTITUDE FT	AVG OAT DEG C	AVG ROTOR SPEED RPM	AVG C_T $\times 10^{-4}$	SAS MODE
□	2800	107.6	6840	21.5	351	35.0	OFF
⊙	2800	107.6	6840	21.5	351	35.0	ON

NOTE: TRIM AIRSPEED = 90 KCAS
LEFT TURNING MANEUVER

SHADED SYMBOLS DENOTE TRIM

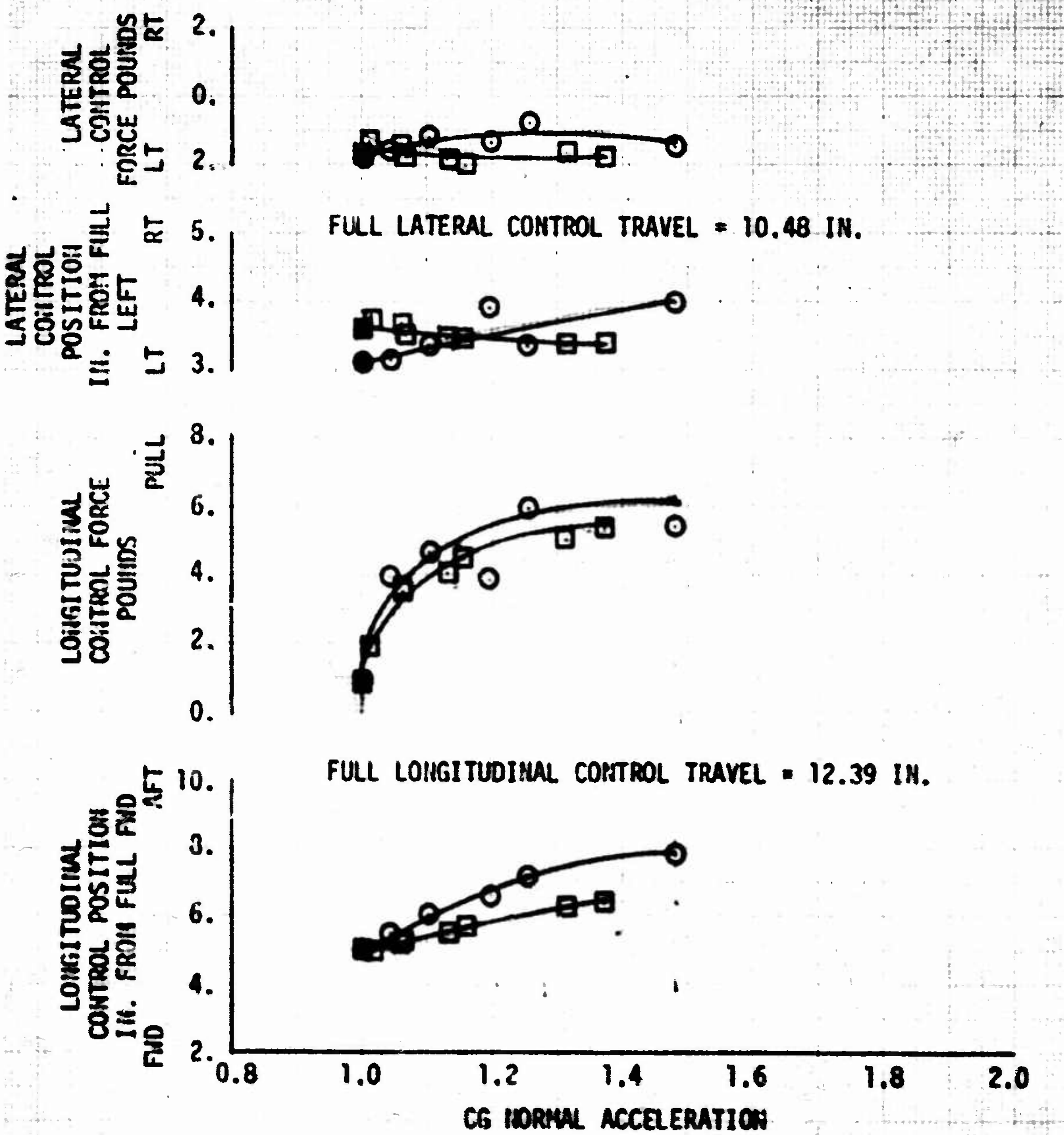


FIGURE 6
LONG PERIOD CHARACTERISTICS
OH-58A USA S/N 68-16708

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L_4} X10	SAS MODE
2630	107.7	6740	20.0	352	88	35.0	ON (TRIM OFF)

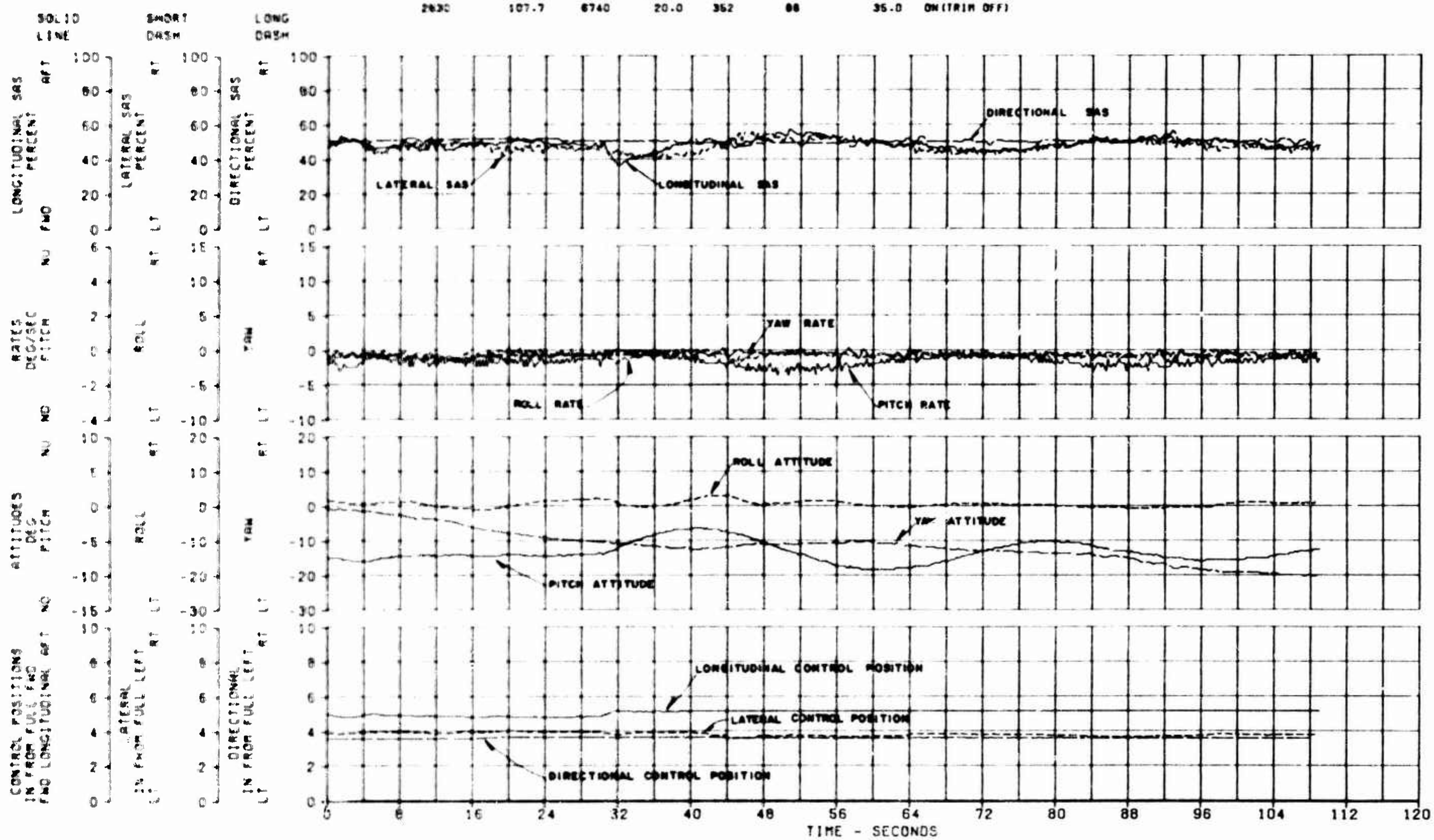


FIGURE 7

LONG PERIOD CHARACTERISTICS

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L_4} X10	SAS MODE
2610	107.6	6730	20.0	351	61	35.0	ON (CYCLIC OFF)

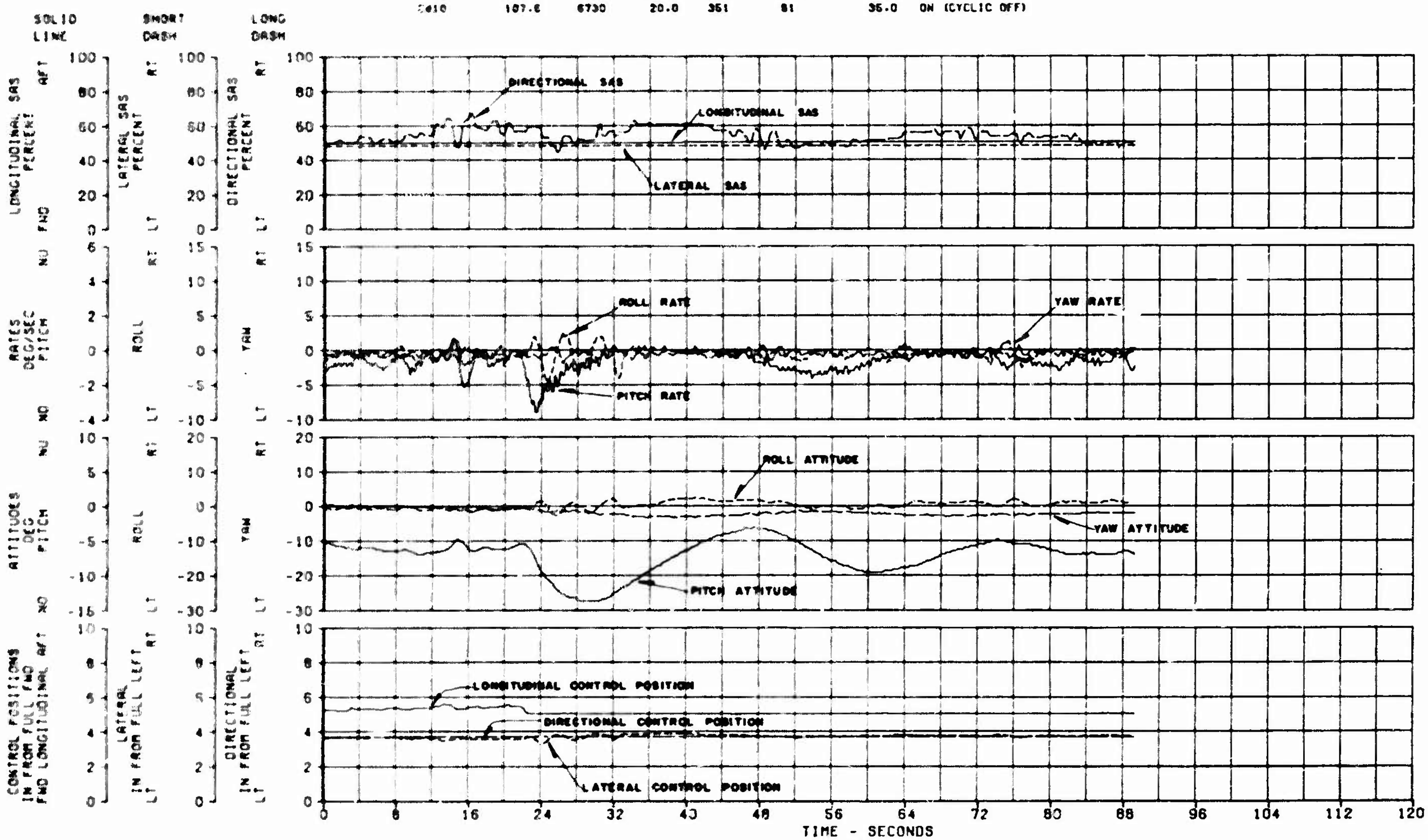


FIGURE 8
LONGITUDINAL PULSE IN LEVEL FLIGHT
OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L_4} X10	SAS MODE
2820	107.7	6800	20.7	352	67	36.0	ON (FORCE TRIM OFF)

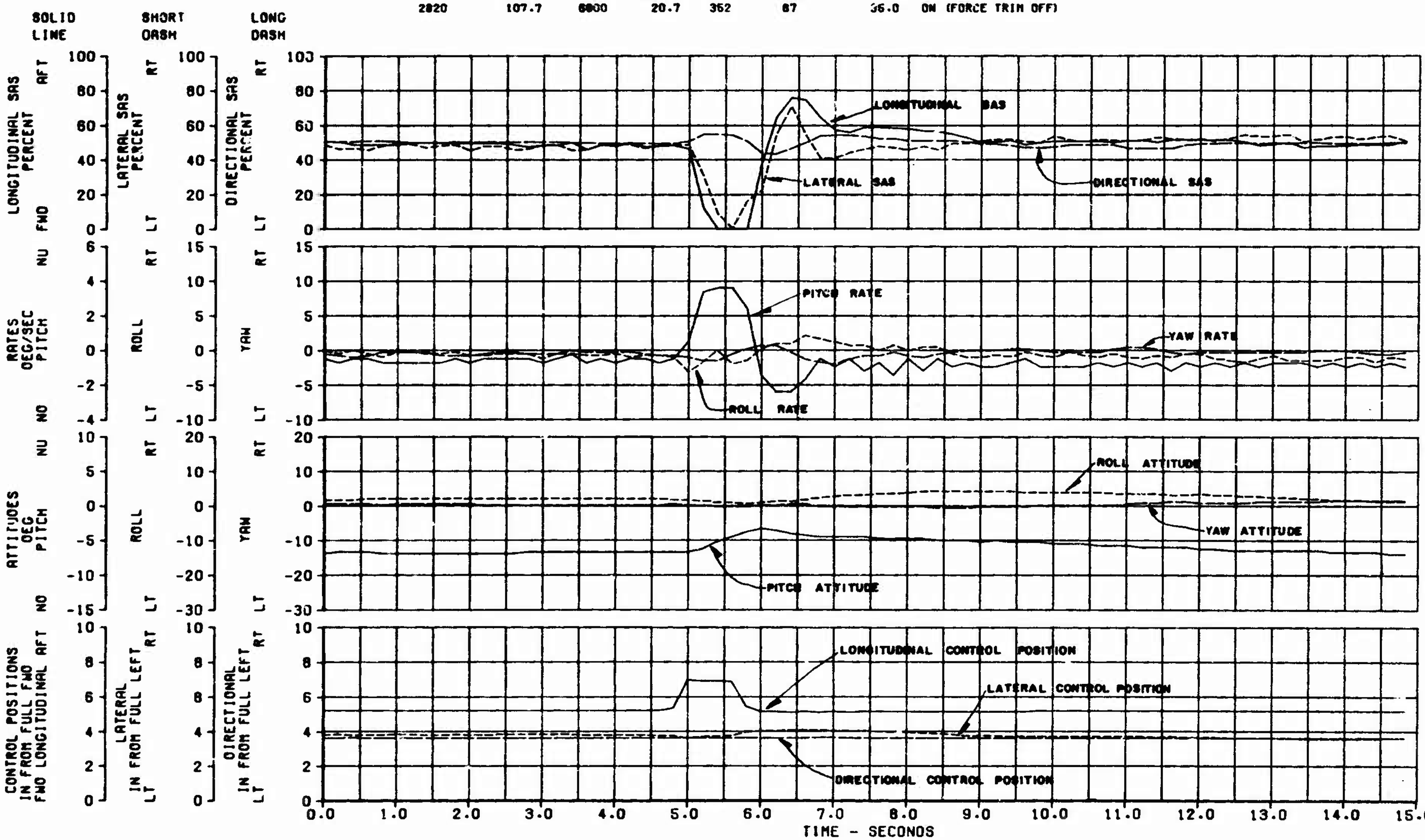


FIGURE 9

LATERAL PULSE IN LEVEL FLIGHT

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_T X10^4	SAS MODE
2810	107.6	6770	20.0	352	87	34.8	ON

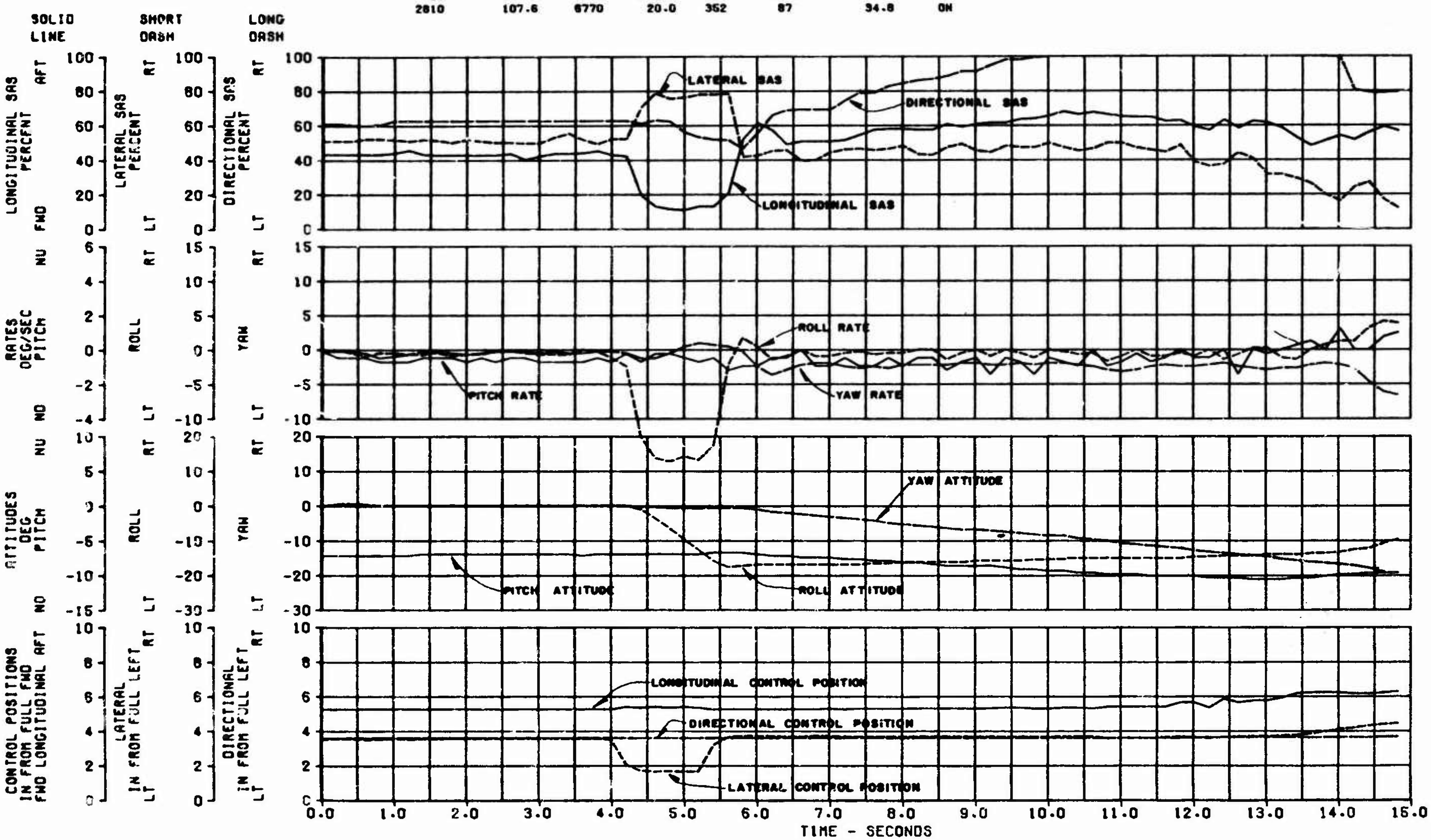


FIGURE 10

DIRECTIONAL PULSE IN LEVEL FLIGHT

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{T} $\times 10^4$	SAS MODE
2970	107.9	9700	19.8	352	97	35.5	ON (TRIM OFF)

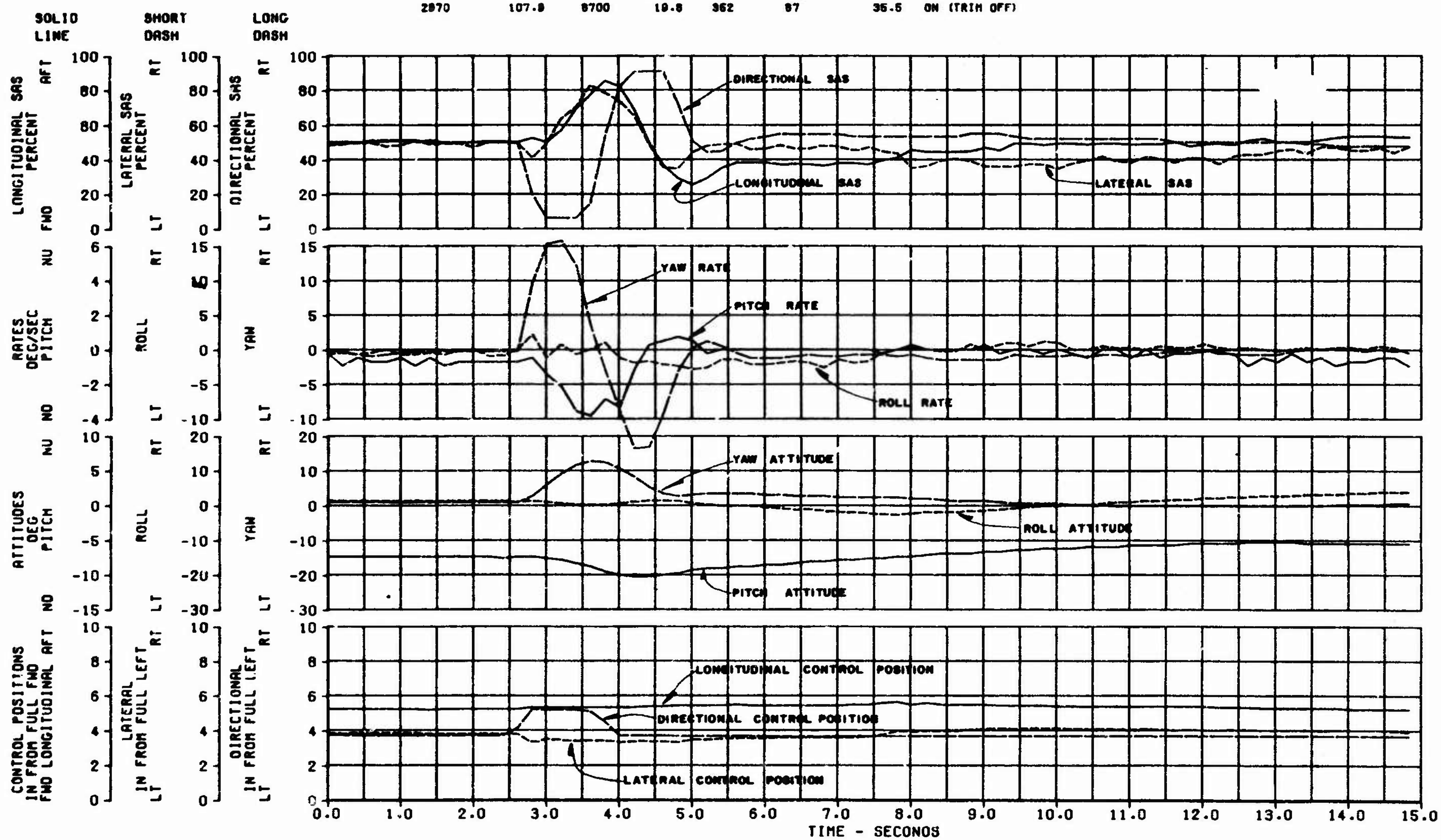


FIGURE 11

LATERAL-DIRECTIONAL OSCILLATION IN LEVEL FLIGHT

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L_4} X10^4	SAS MODE
2790	107.5	6750	20.2	352	85	34.5	OFF

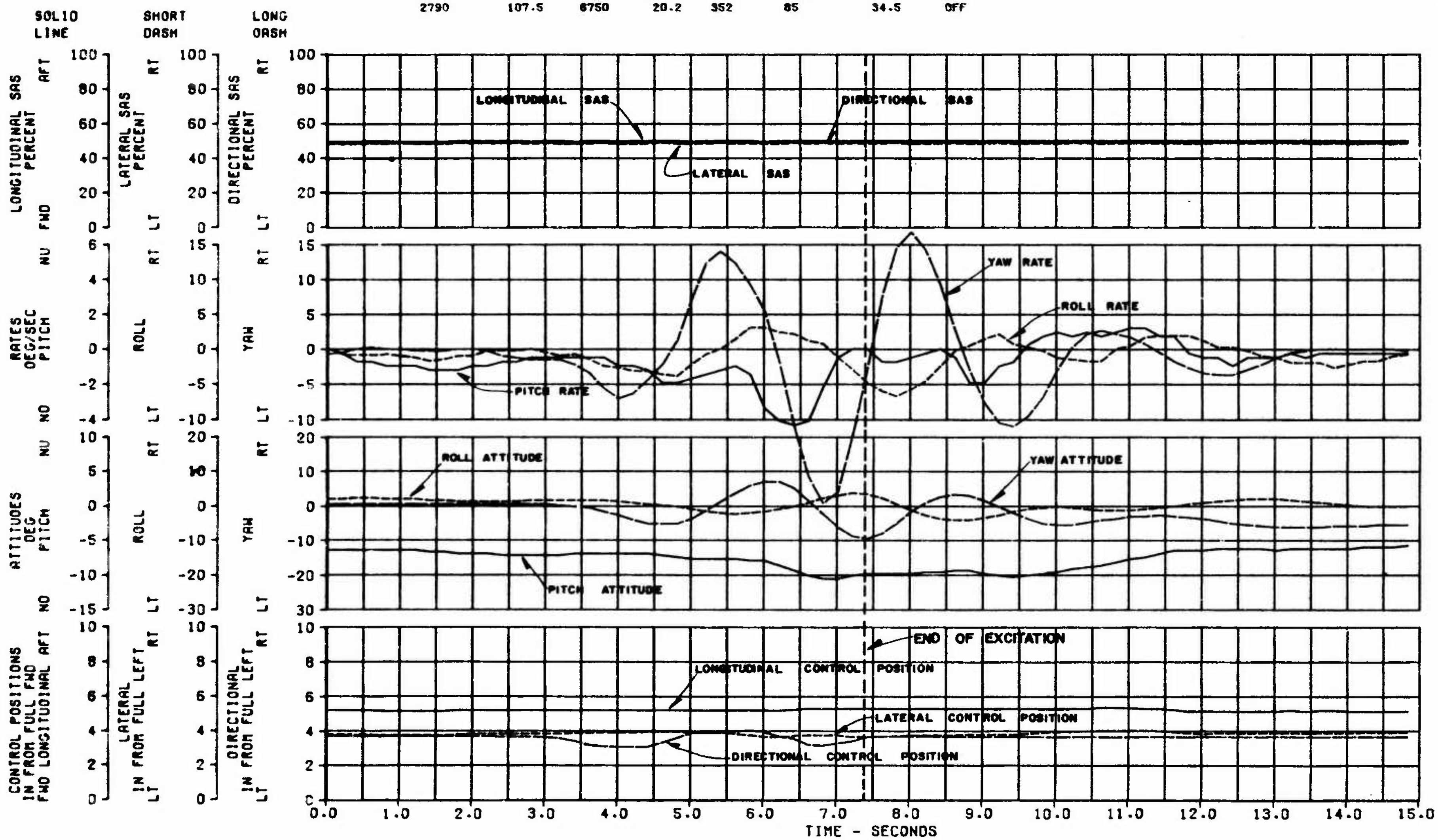


FIGURE 12

LATERAL-DIRECTIONAL OSCILLATION IN LEVEL FLIGHT

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	$C_{T} \times 10^{4}$	SAS MODE
2870	137.9	6740	20.1	353	66	35.5	ON

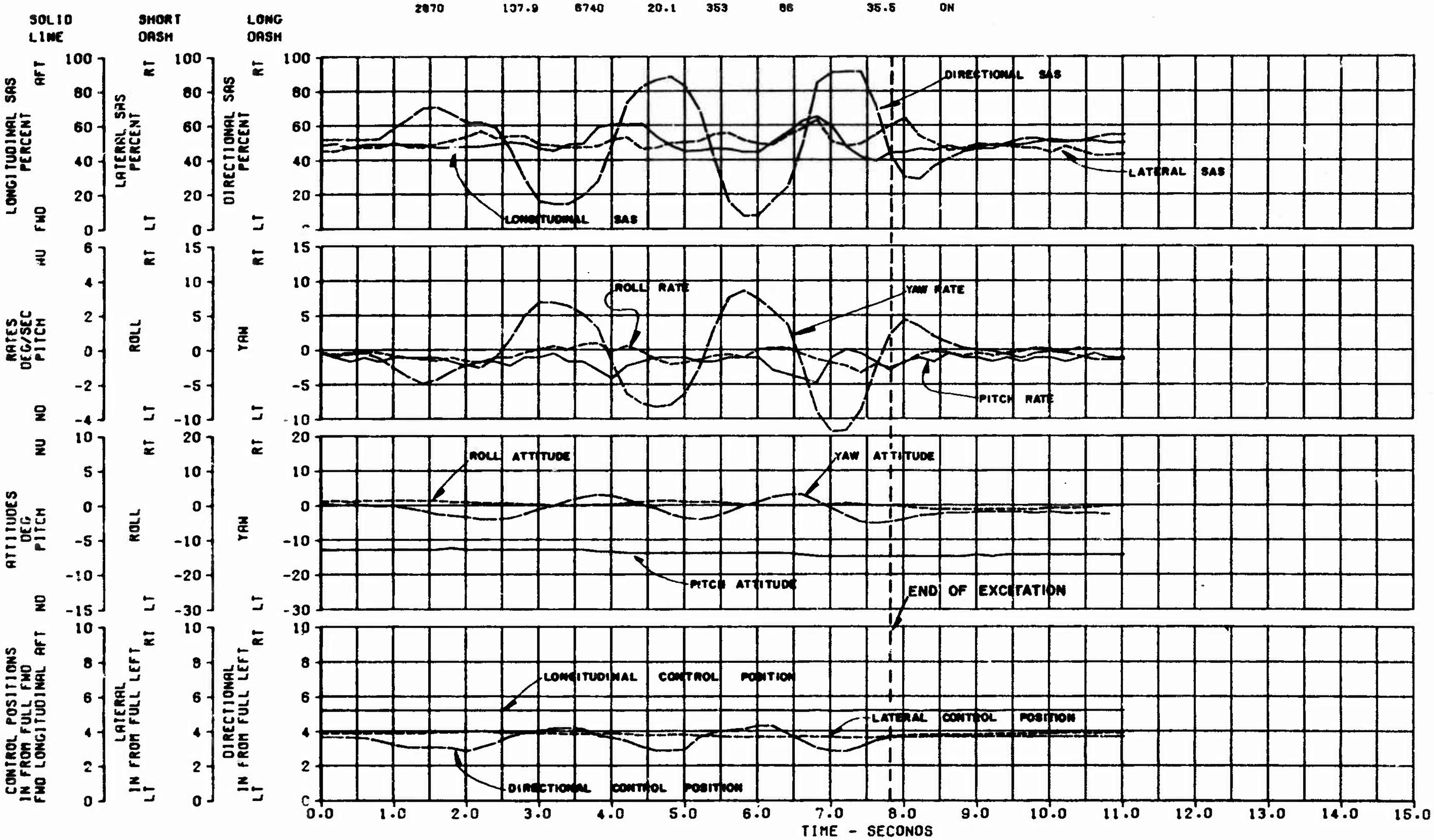


FIGURE 13
LONGITUDINAL CONTROL RESPONSE AND SENSITIVITY

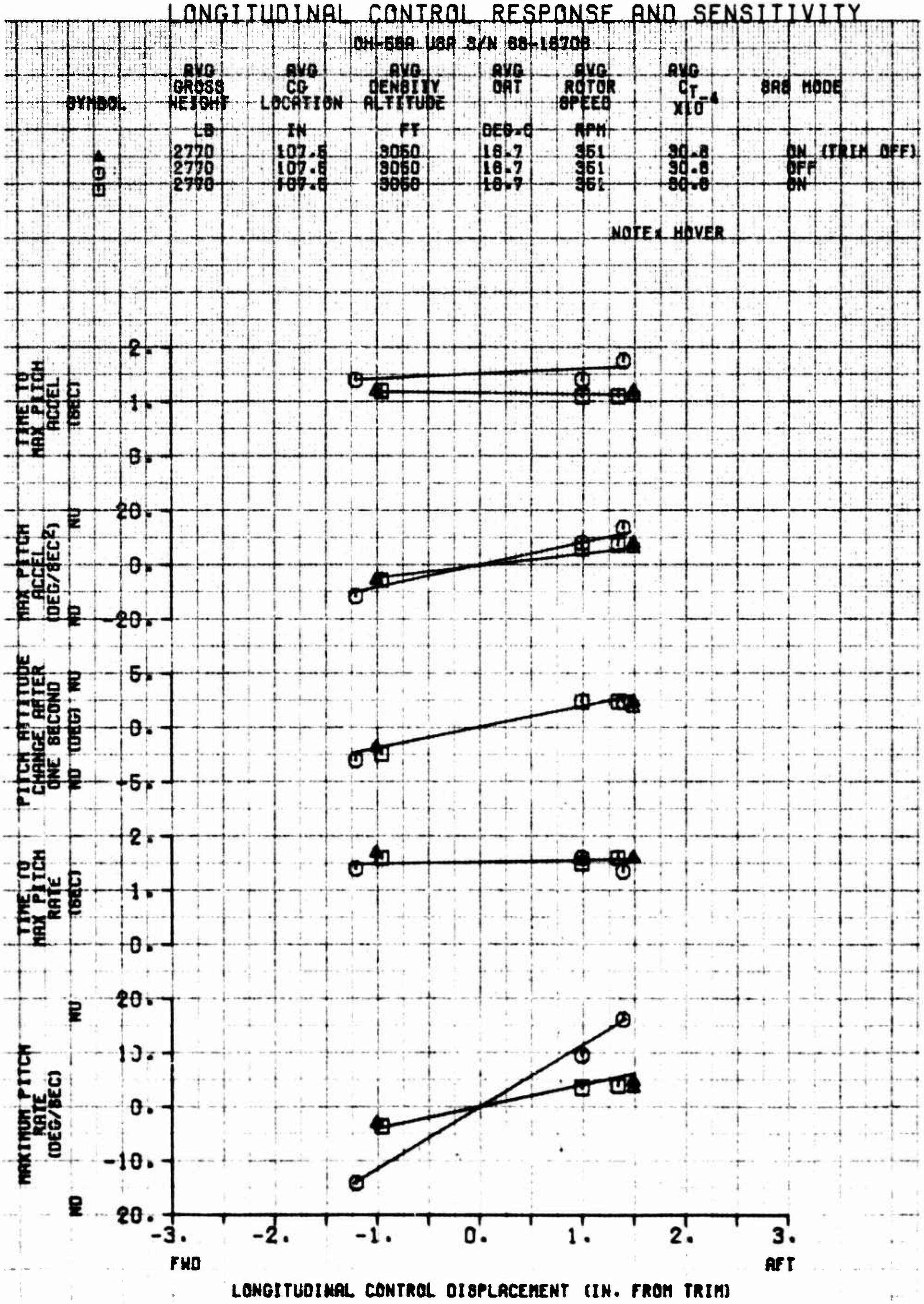


FIGURE 14

LATERAL CONTROL RESPONSE AND SENSITIVITY

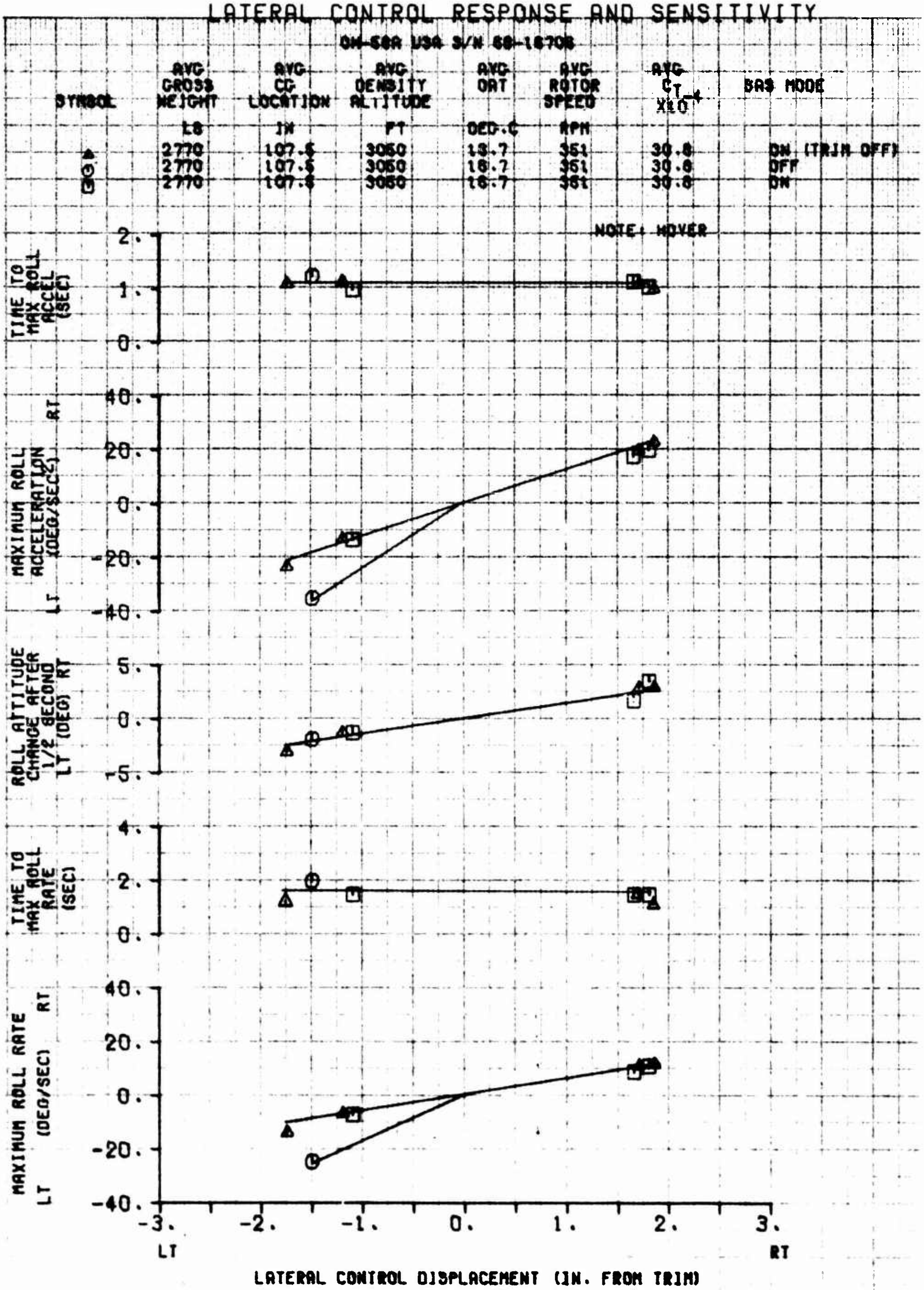


FIGURE 15

DIRECTIONAL CONTROL RESPONSE AND SENSITIVITY

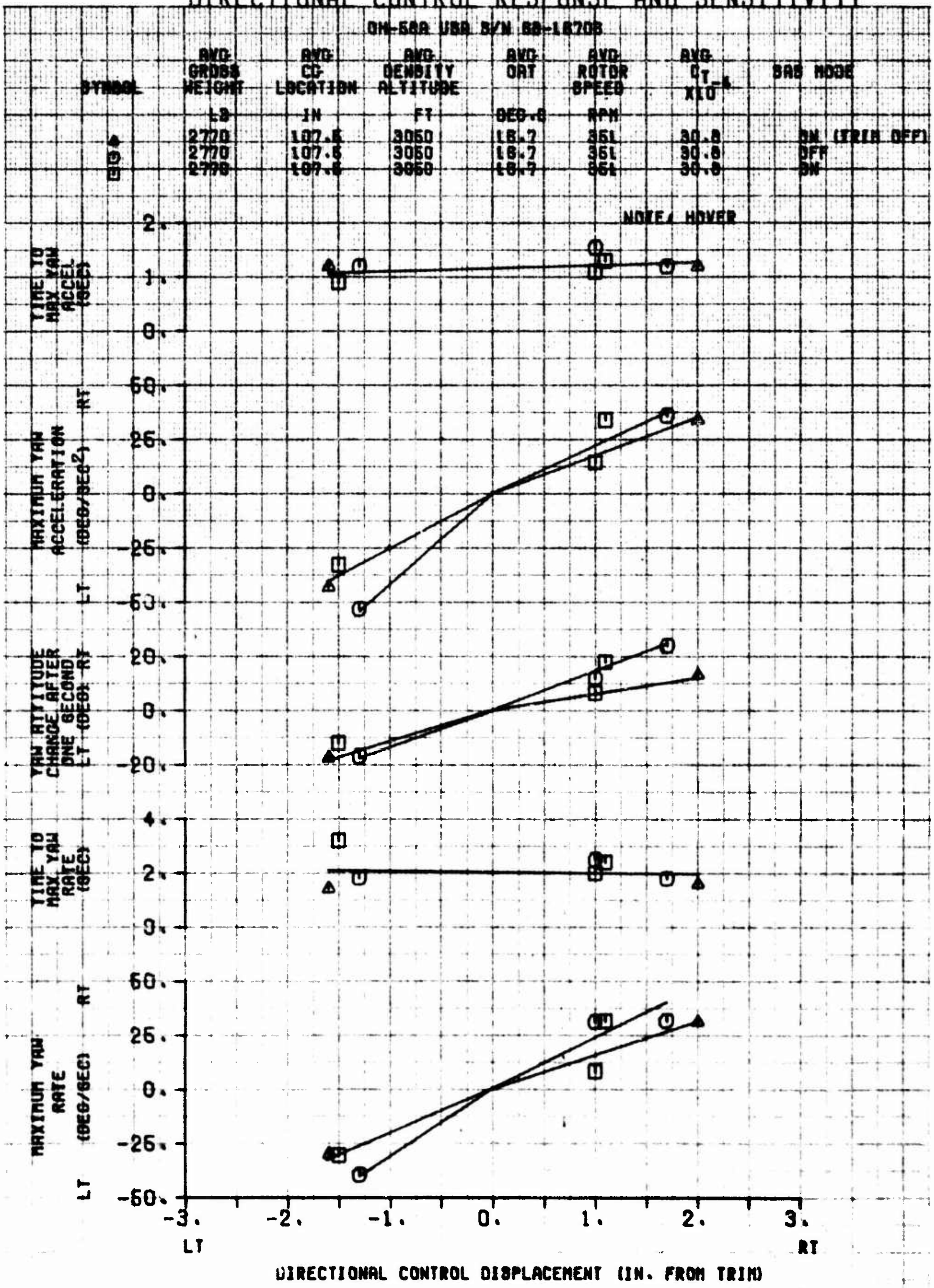


FIGURE 16

LONGITUDINAL CONTROL RESPONSE AND SENSITIVITY

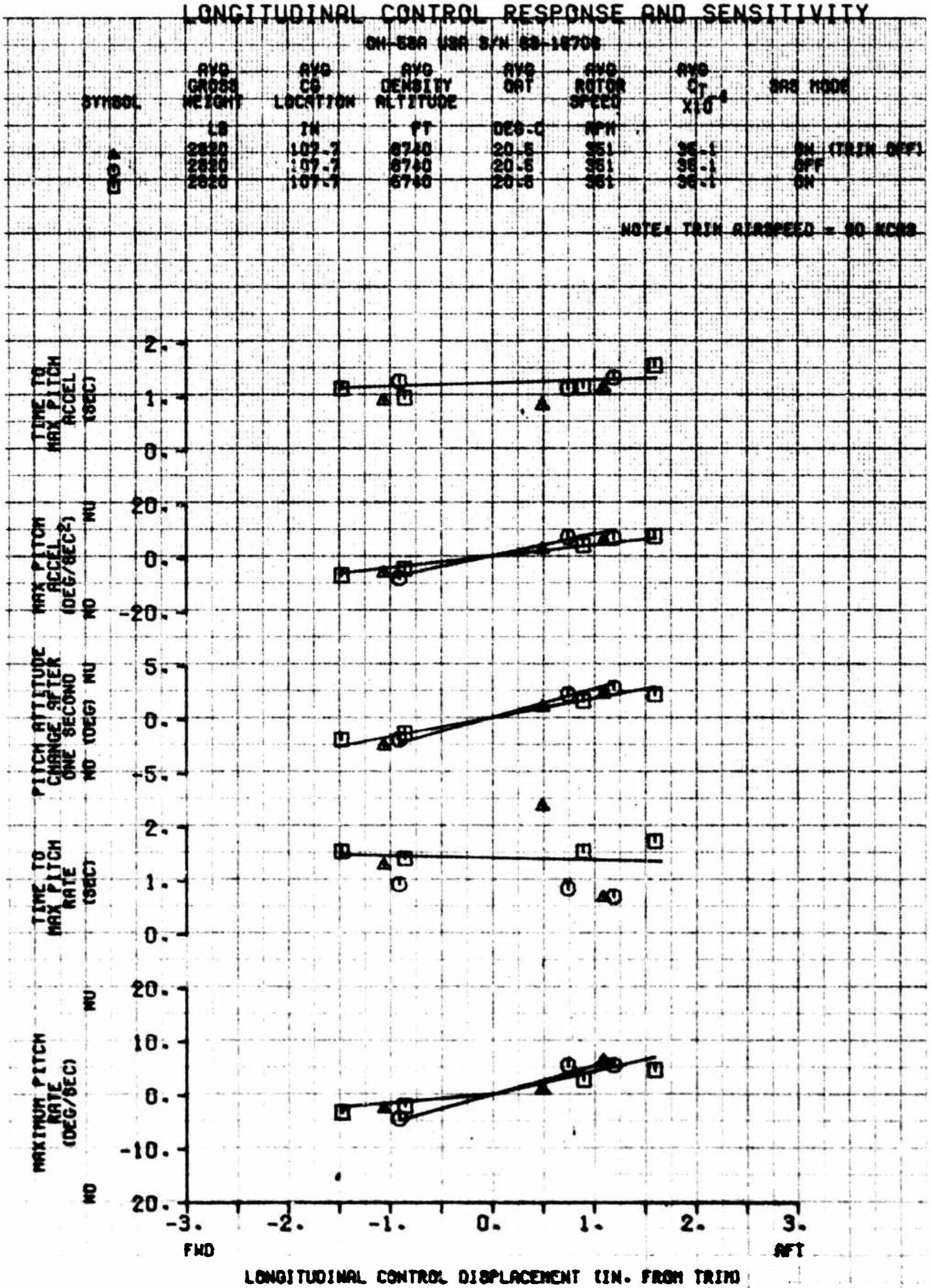


FIGURE 17

LATERAL CONTROL RESPONSE AND SENSITIVITY

OH-58A USA S/N 68-16708

SYMBOL	AVG GROSS WEIGHT (LB)	AVG CG LOCATION (IN)	AVG DENSITY ALTITUDE (FT)	AVG OAT (DEG-C)	AVG ROTOR SPEED (RPM)	AVG $C_T \times 10^{-4}$	SAS MODE
▲	2820	107.7	6740	20.5	351	38.1	ON (TRIM OFF)
○	2820	107.7	6740	20.5	351	38.1	OFF
□	2820	107.7	6740	20.5	351	38.1	ON

NOTE: TRIM AIRSPEED = 90 KCAS

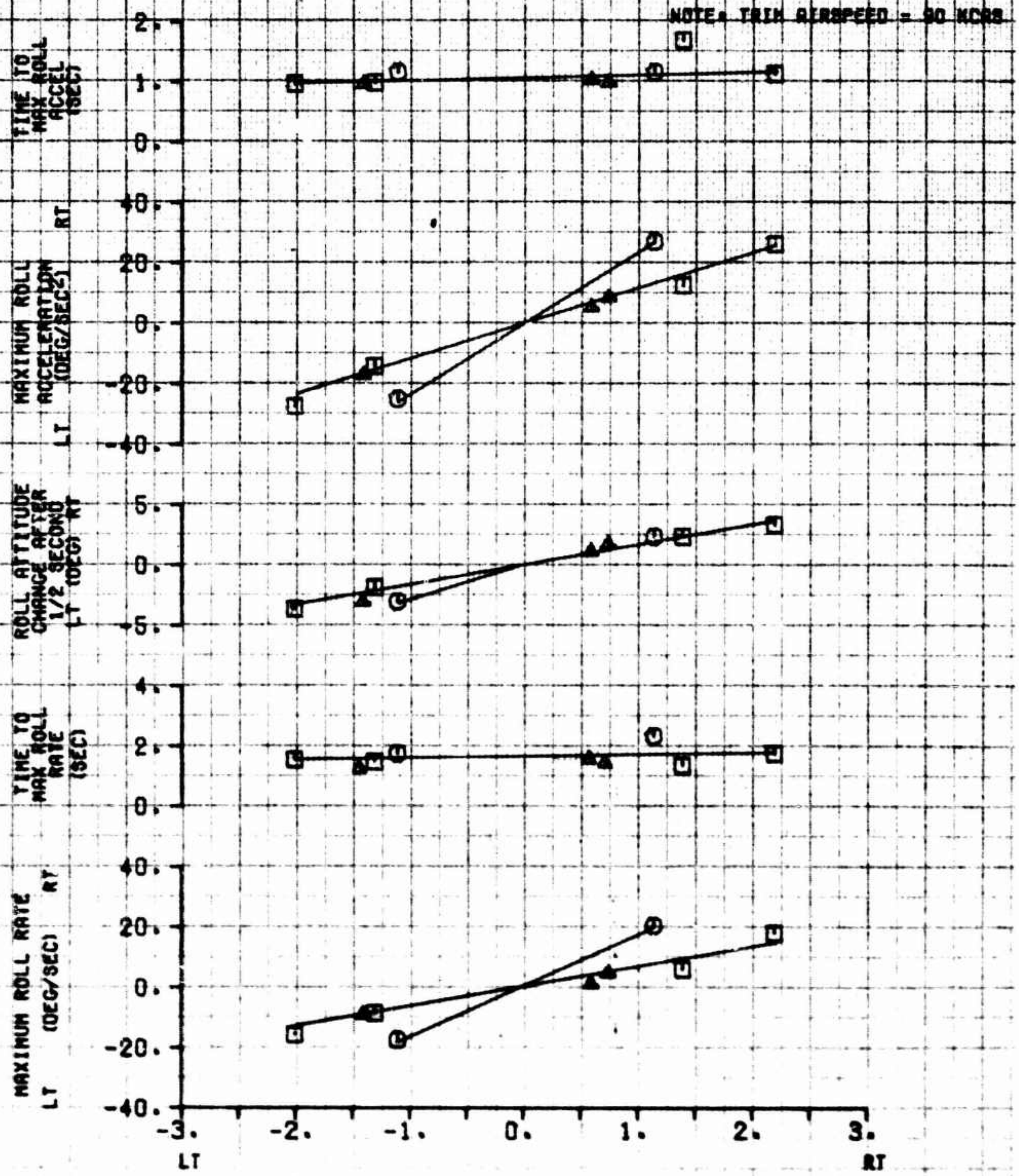


FIGURE 18
DIRECTIONAL CONTROL RESPONSE AND SENSITIVITY

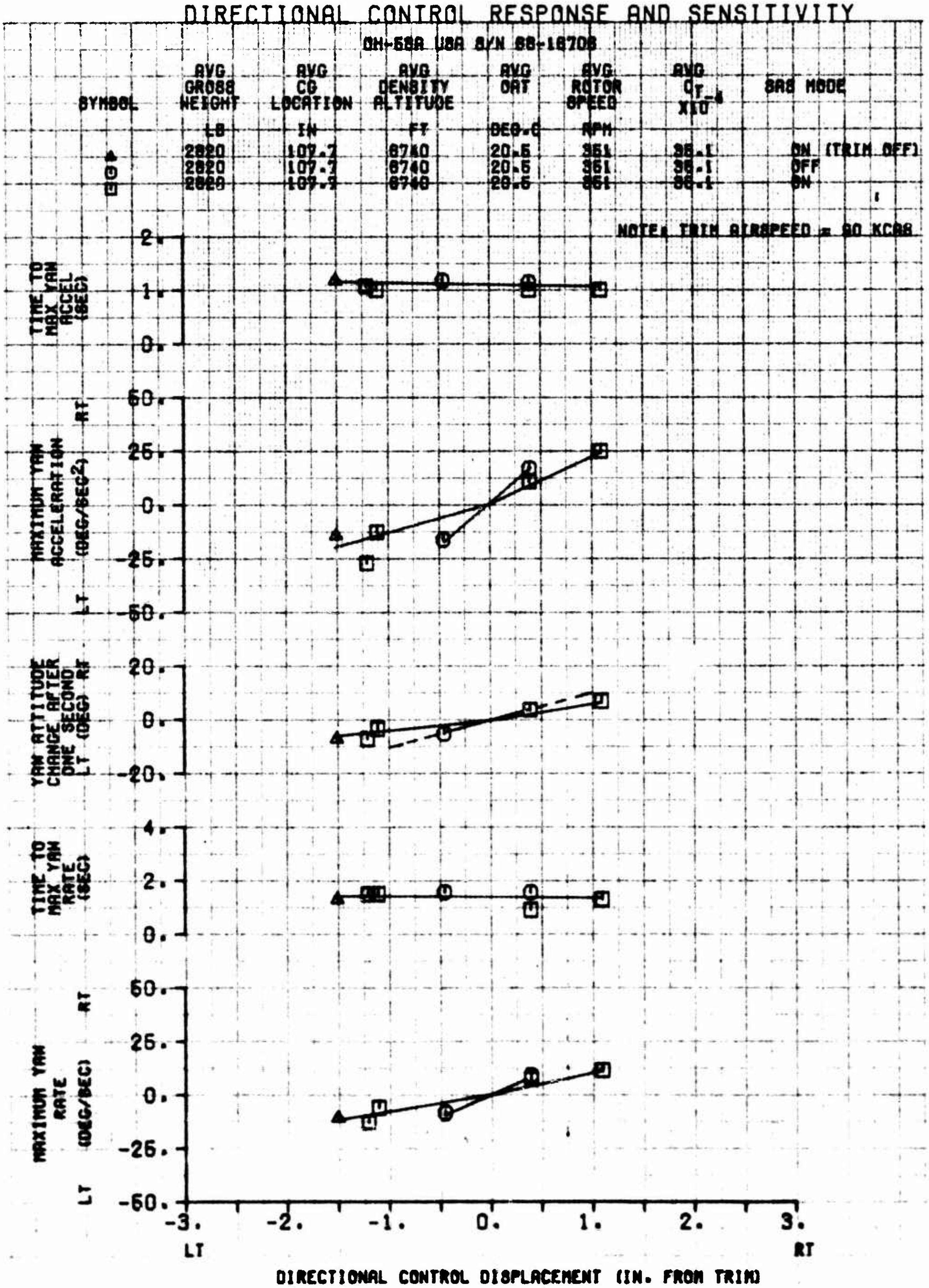


FIGURE 19
AUTOROTATIONAL ENTRY FROM LEVEL FLIGHT
OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L_4} X10	SAS MODE
2900	107.6	6680	19.5	353	87	34.4	ON

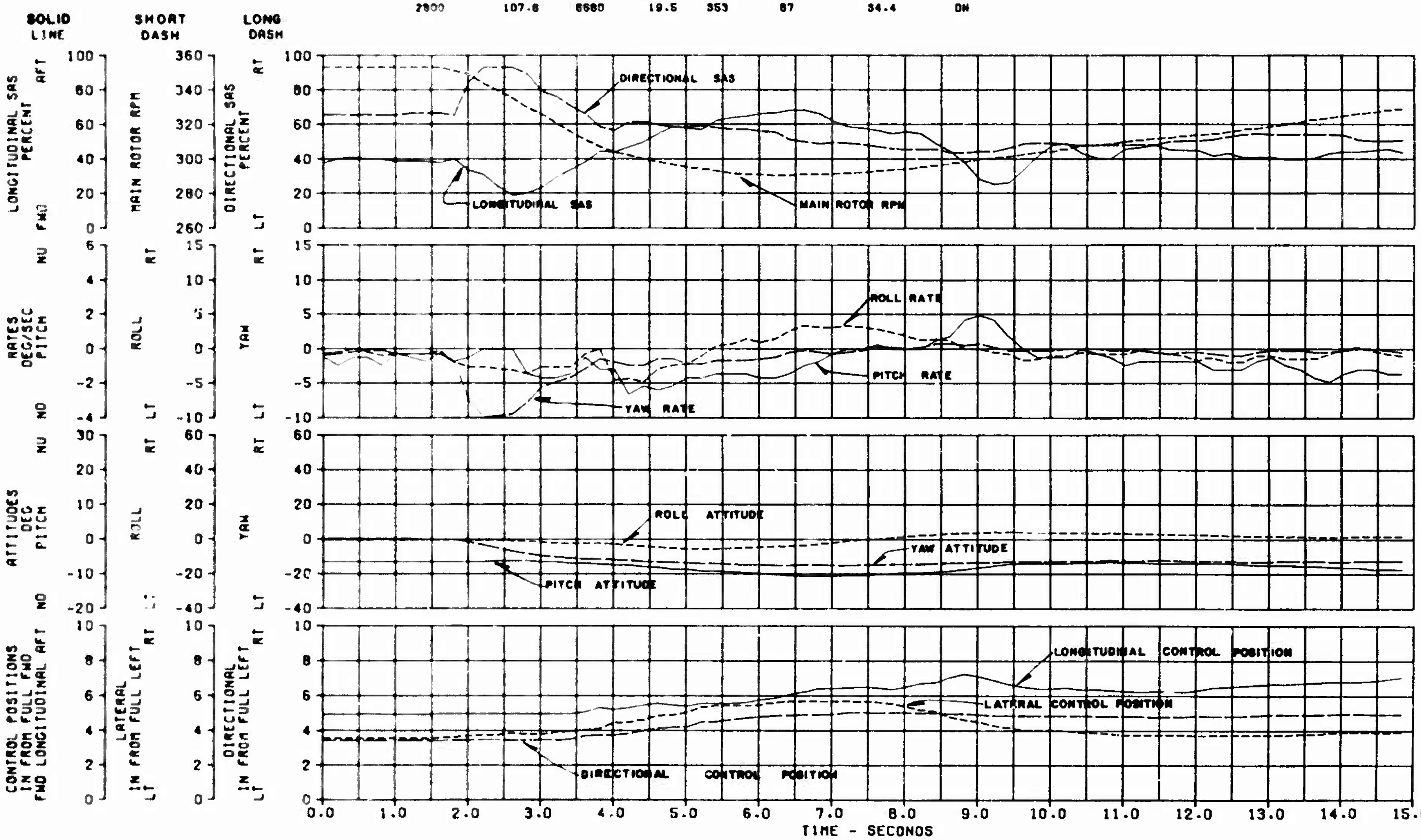


FIGURE 20

LONGITUDINAL SAS HARDOVER IN LEVEL FLIGHT

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L_4} X10	SAS MODE
2800	107.6	6640	21.5	351	96	35.0	ON

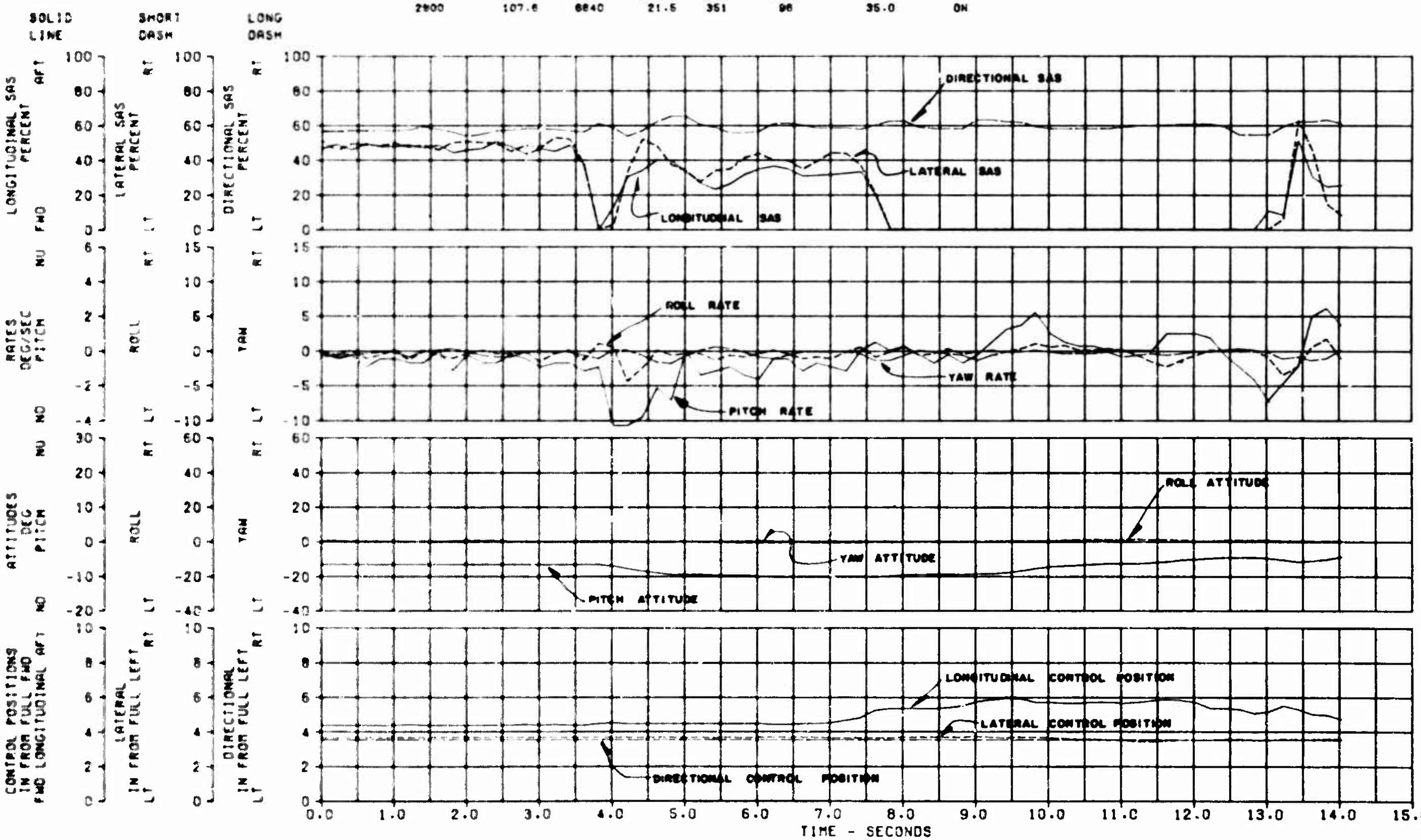


FIGURE 21

DIRECTIONAL SAS HARDOVER IN LEVEL FLIGHT

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{T} $\times 10^{4}$	SAS MODE
2770	107.5	6870	21.2	351	96	35.0	ON

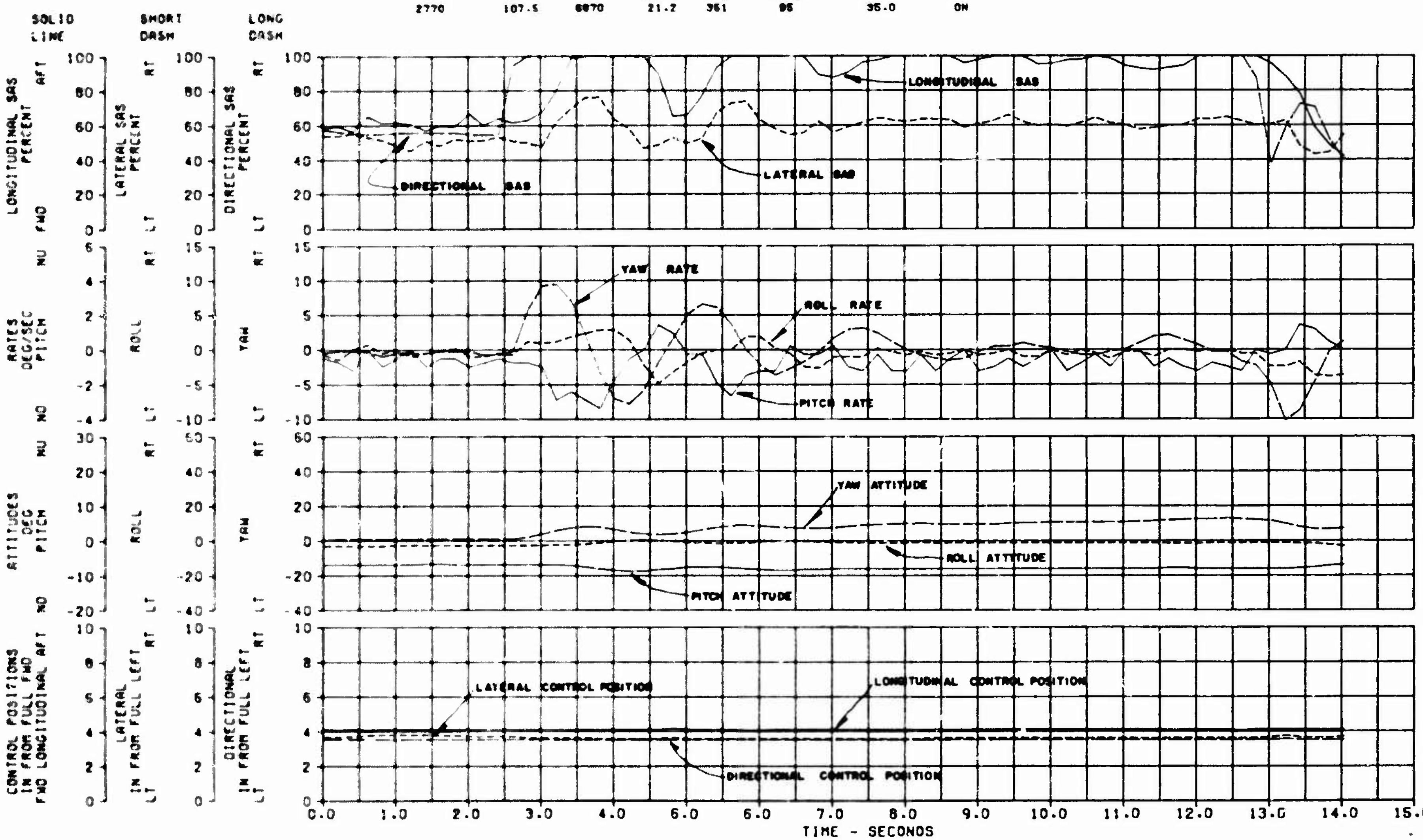


FIGURE 22

LATERAL SAS HARDOVER IN LEVEL FLIGHT

OH-58A USA S/N 68-16708

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_T X10^4	SAS MODE
2790	107.5	6840	21.5	351	95	34.6	ON

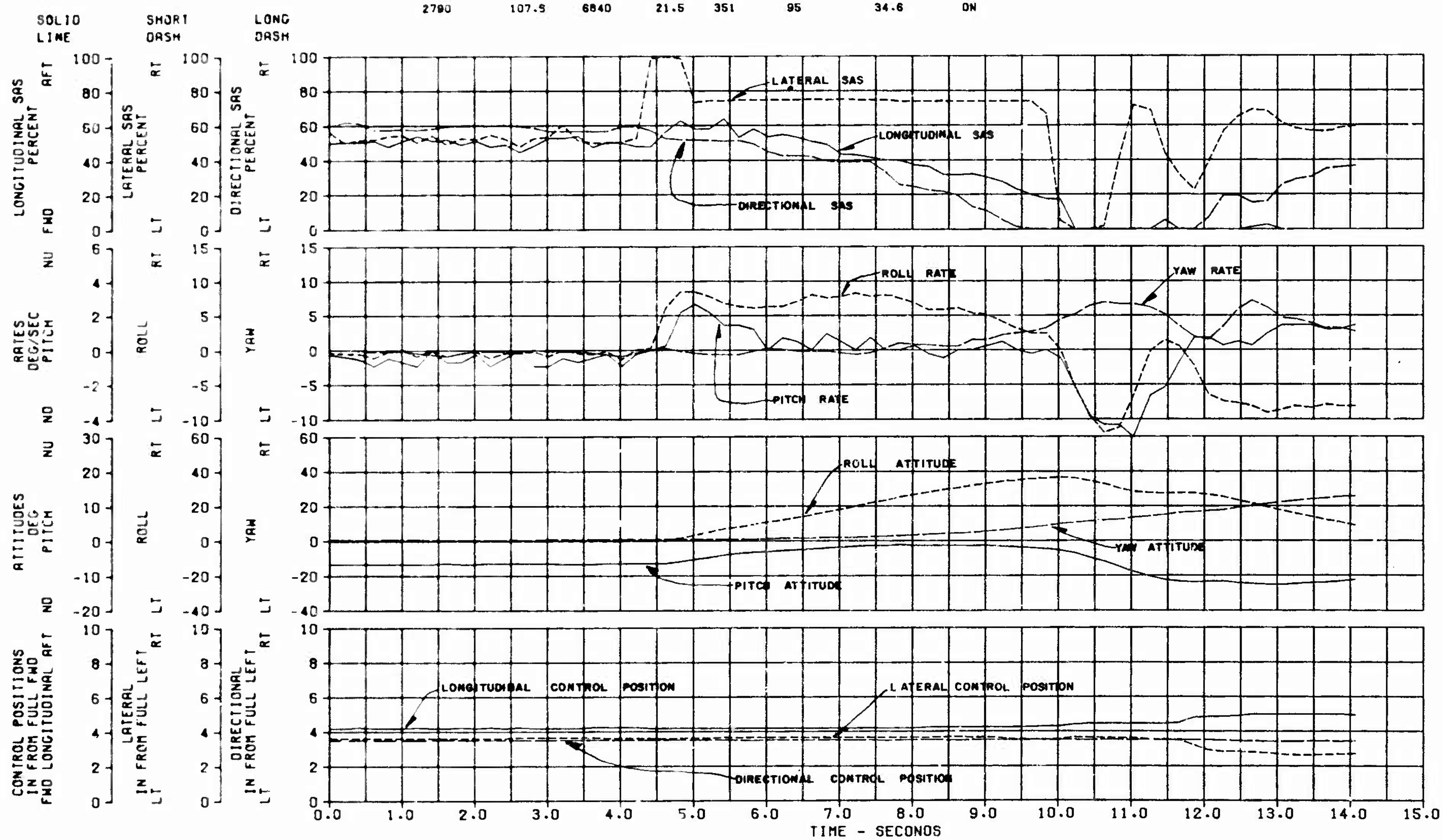


FIGURE 23

LATERAL SAS HARDOVER IN LEVEL FLIGHT

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L} $X10^{4}$	SAS MODE
2790	107.6	6740	21.3	351	95	34.7	ON

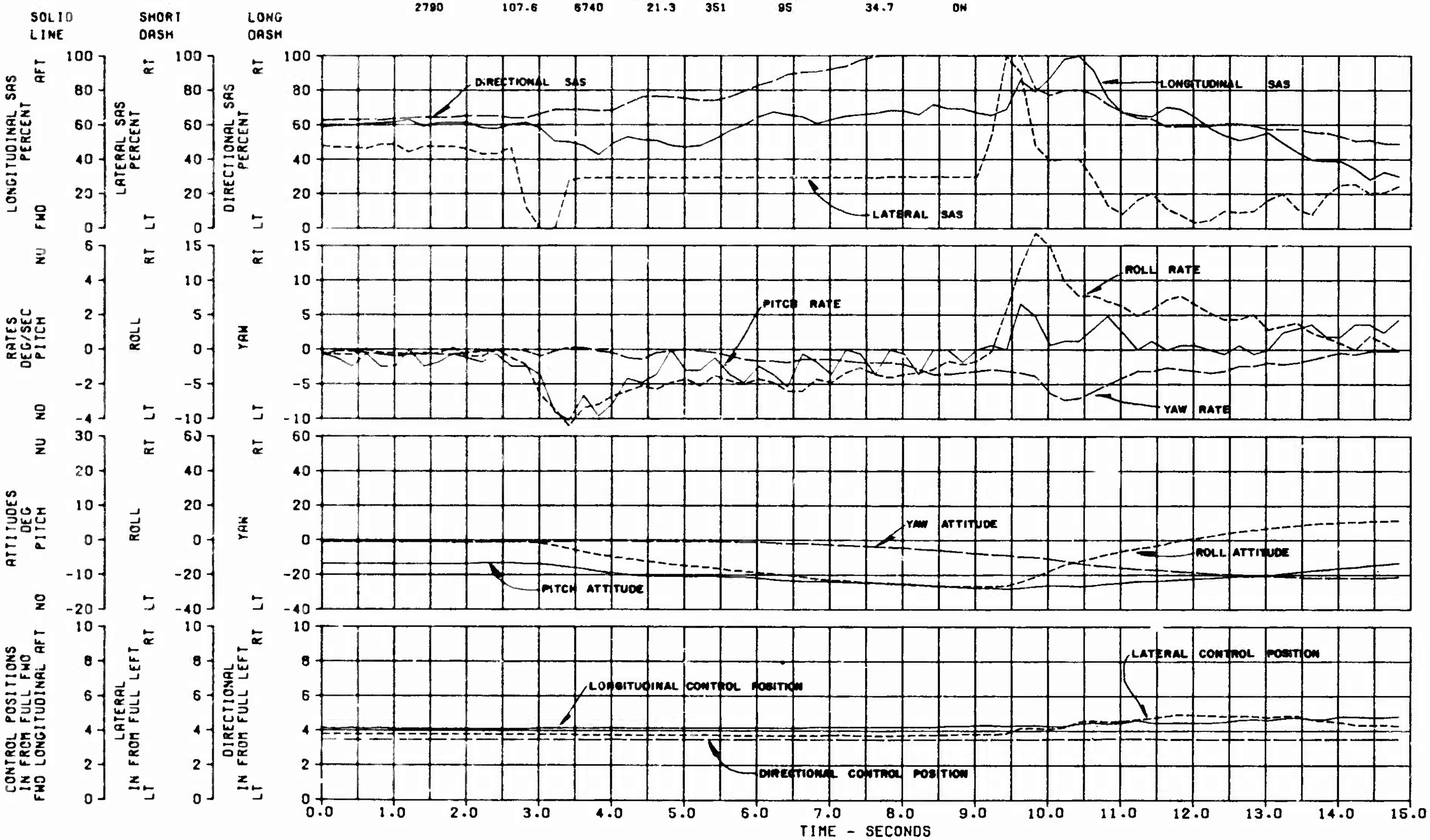


FIGURE 24

LONGITUDINAL SAS HARDOVER IN HOVER

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L_4} X10	SAS MODE
2770	107.5	5050	18.7	351	0	30.8	ON

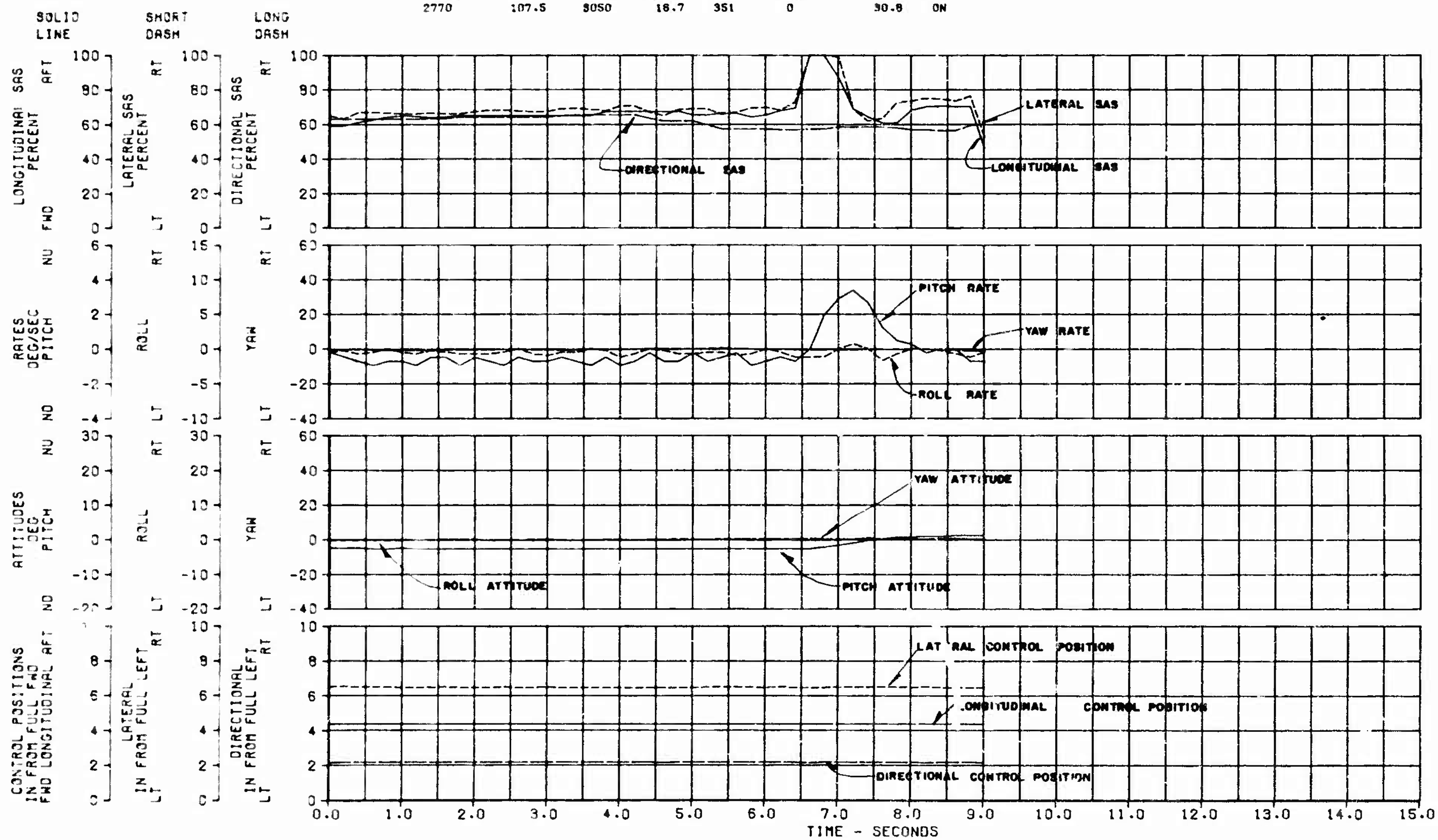


FIGURE 25
LATERAL SAS HARDOVER IN HOVER
OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{L} X10[4]	SAS MODE
2730	107.4	3130	17.3	351	0	30.4	ON

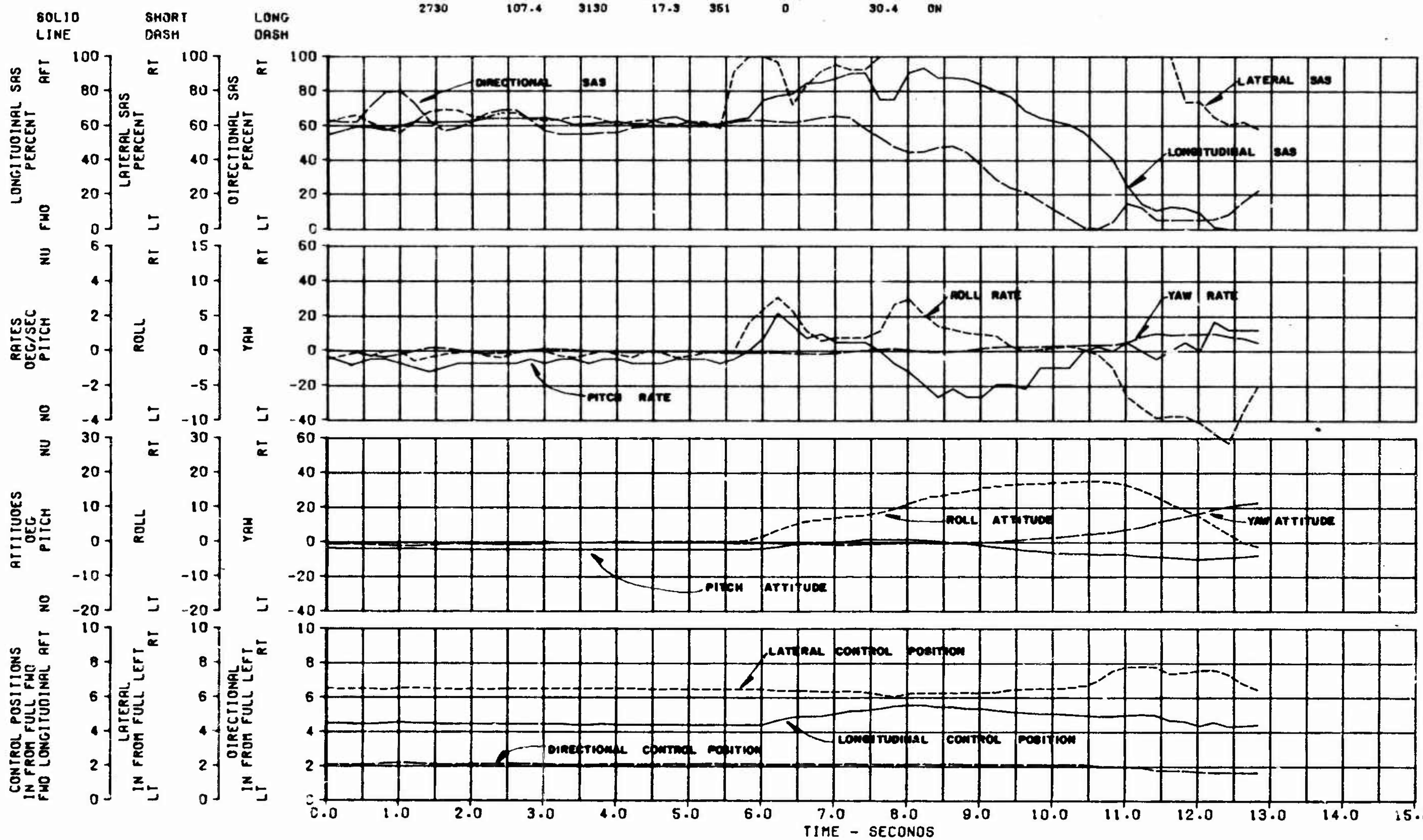


FIGURE 26

DIRECTIONAL SAS FAILURES IN HOVER

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{T_4} X10	SAS MODE
2790	107.6	2800	15.3	351	0	30.8	ON

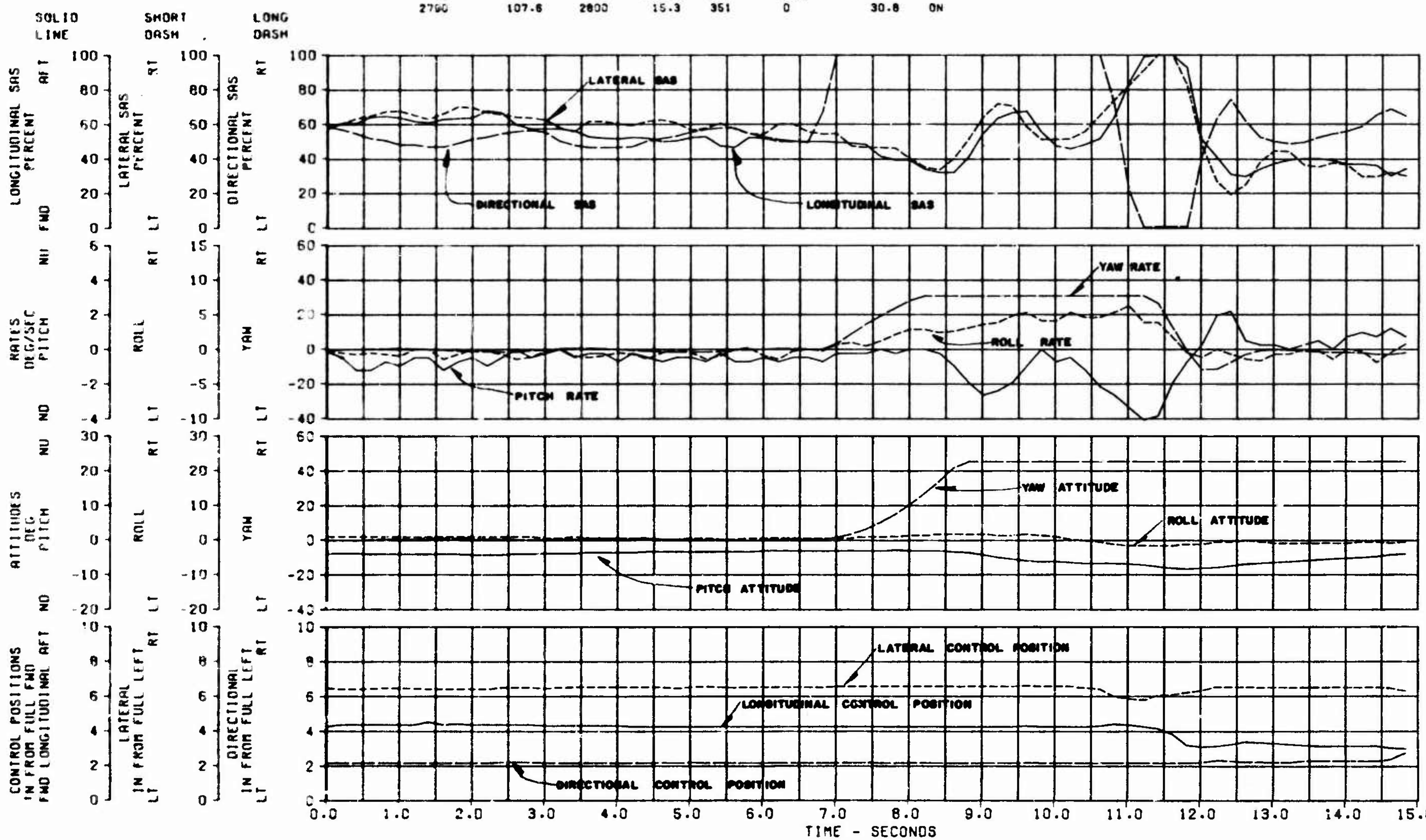
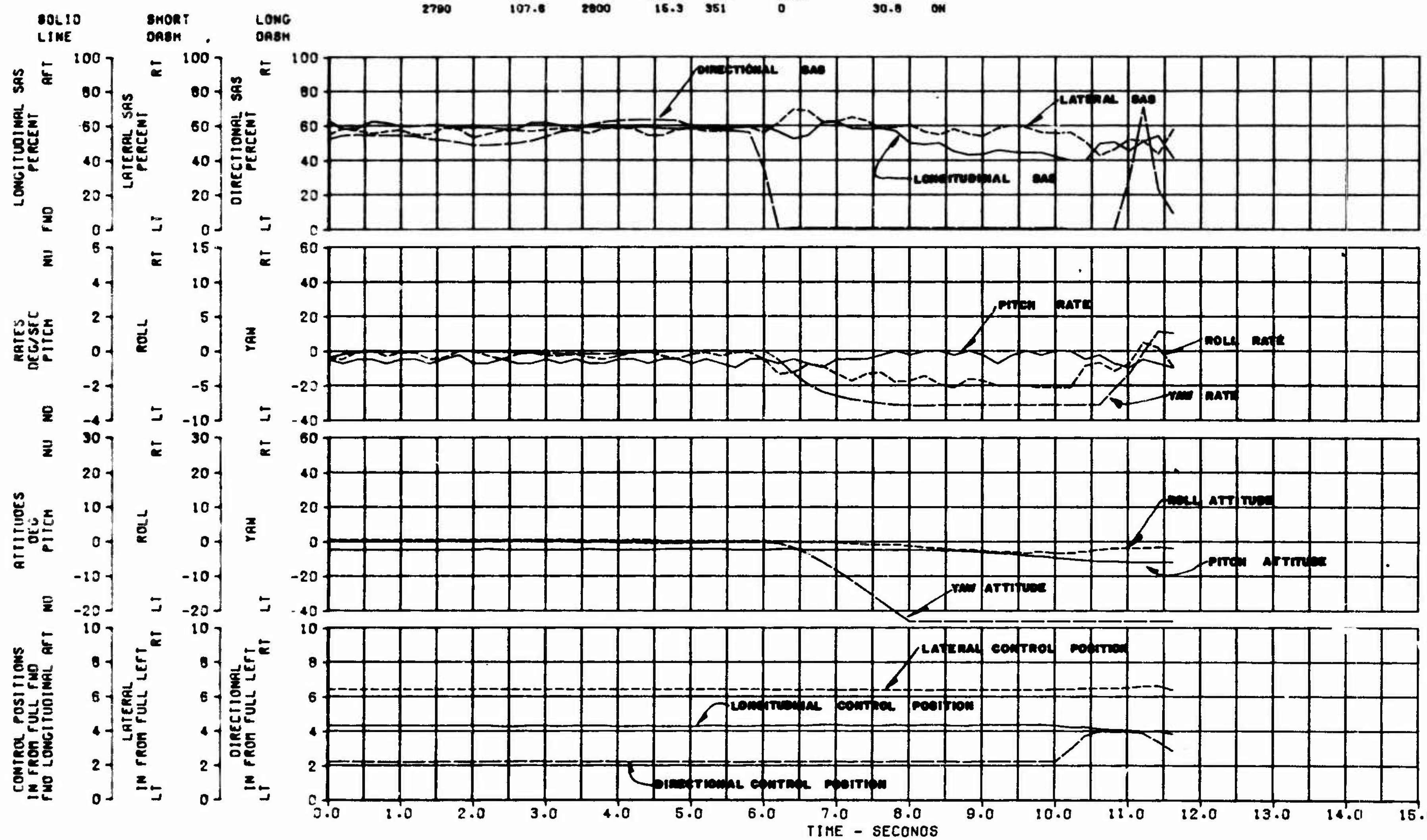


FIGURE 27

DIRECTIONAL SAS FAILURES IN HOVER

OH-58A USA S/N 68-16706

GROSS WEIGHT LB	CG LOCATION IN.	DENSITY ALTITUDE FT.	OAT DEG C	ROTOR SPEED RPM	TRIM AIRSPEED KCAS	C_{T_4} X10	SAS MODE
2790	107.6	2800	16.3	351	0	30.8	ON



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